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(54) STACKED BULK ACOUSTIC RESONATOR COMPRISING A BRIDGE AND AN ACOUSTIC REFLECTOR ALONG A PERIMETER OF THE RESONATOR

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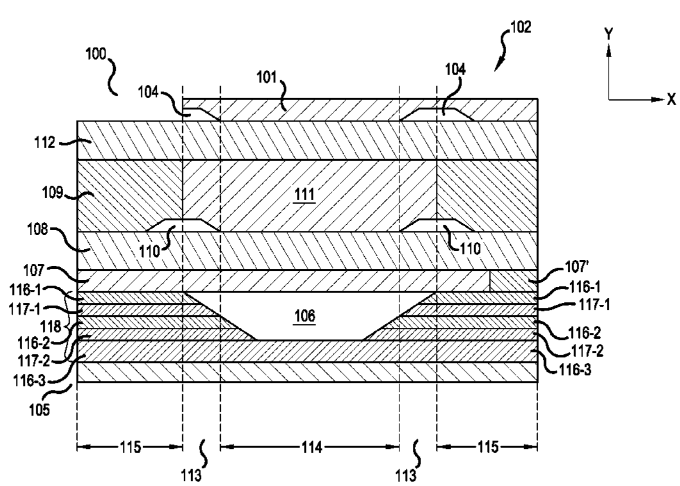
(57) **ABSTRACT**

In a representative embodiment, a bulk acoustic wave (BAW) resonator comprises: a cavity provided in a first layer and having a perimeter bordering an active region of the BAW resonator, a distributed Bragg reflector (DBR) bordering the cavity, wherein the first layer is one of the layers of the DBR; a first electrode disposed over the substrate; a first piezoelectric layer disposed over the first electrode; a second electrode disposed over the first piezoelectric layer; a second piezoelectric layer disposed over the second electrode; a third electrode disposed over the second piezoelectric layer; and a bridge disposed between the first electrode and the third electrode.

41 Claims, 23 Drawing Sheets



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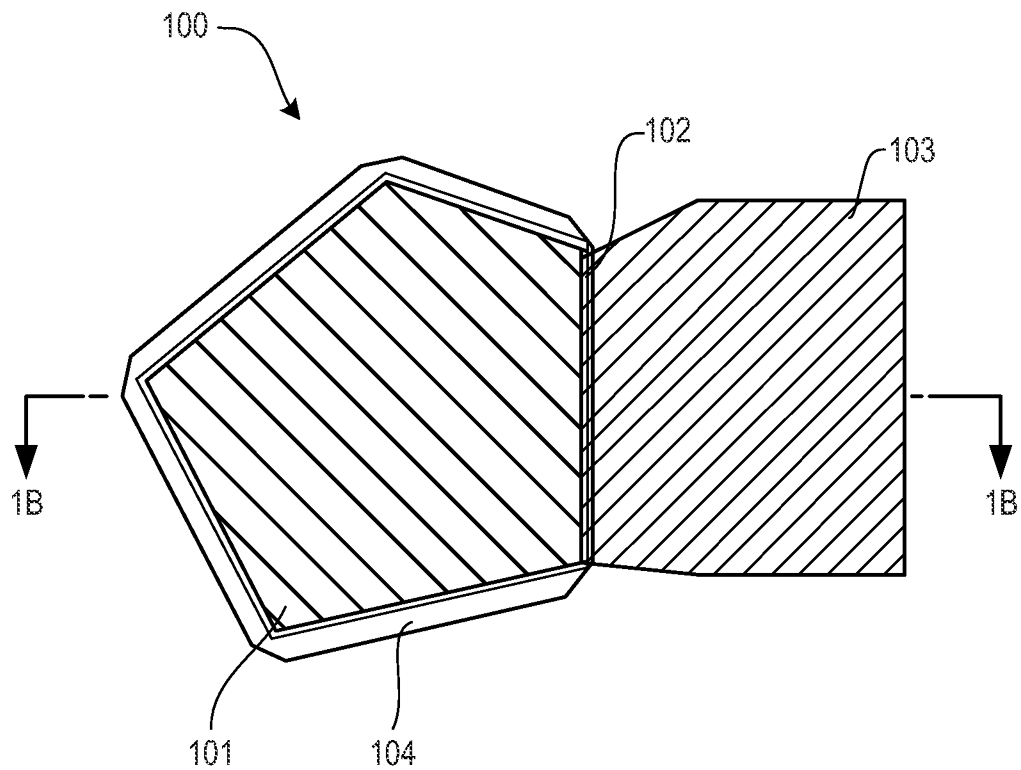

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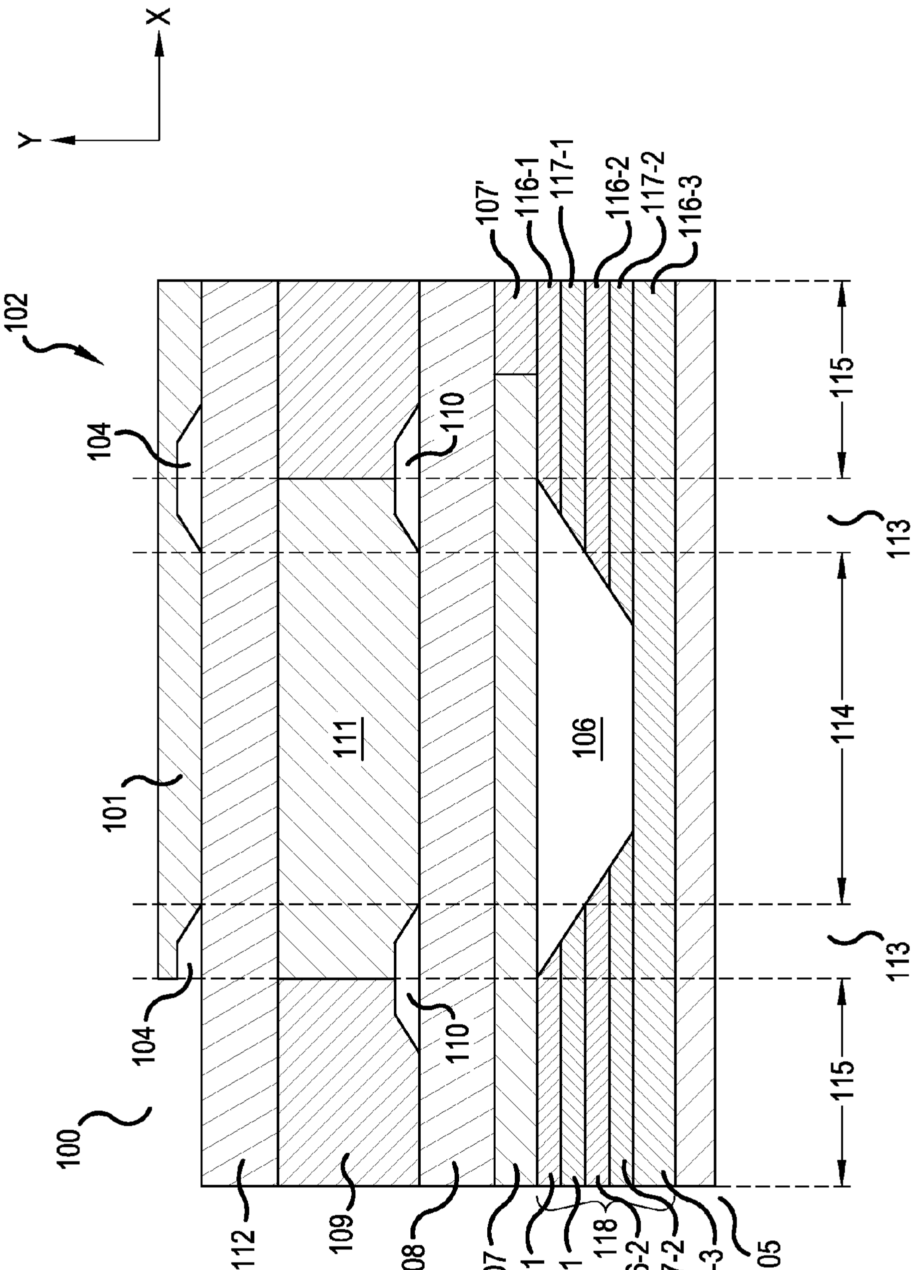
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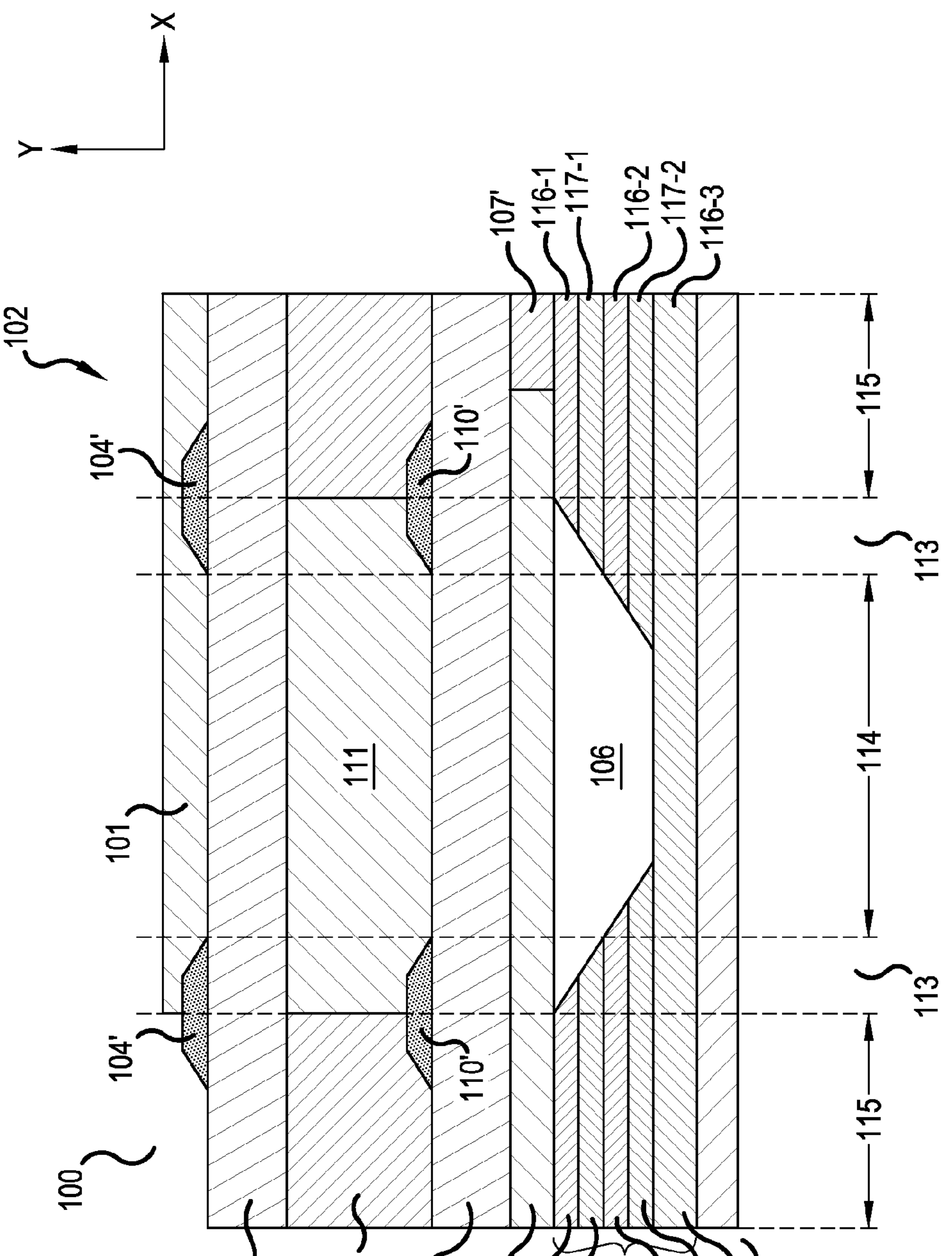
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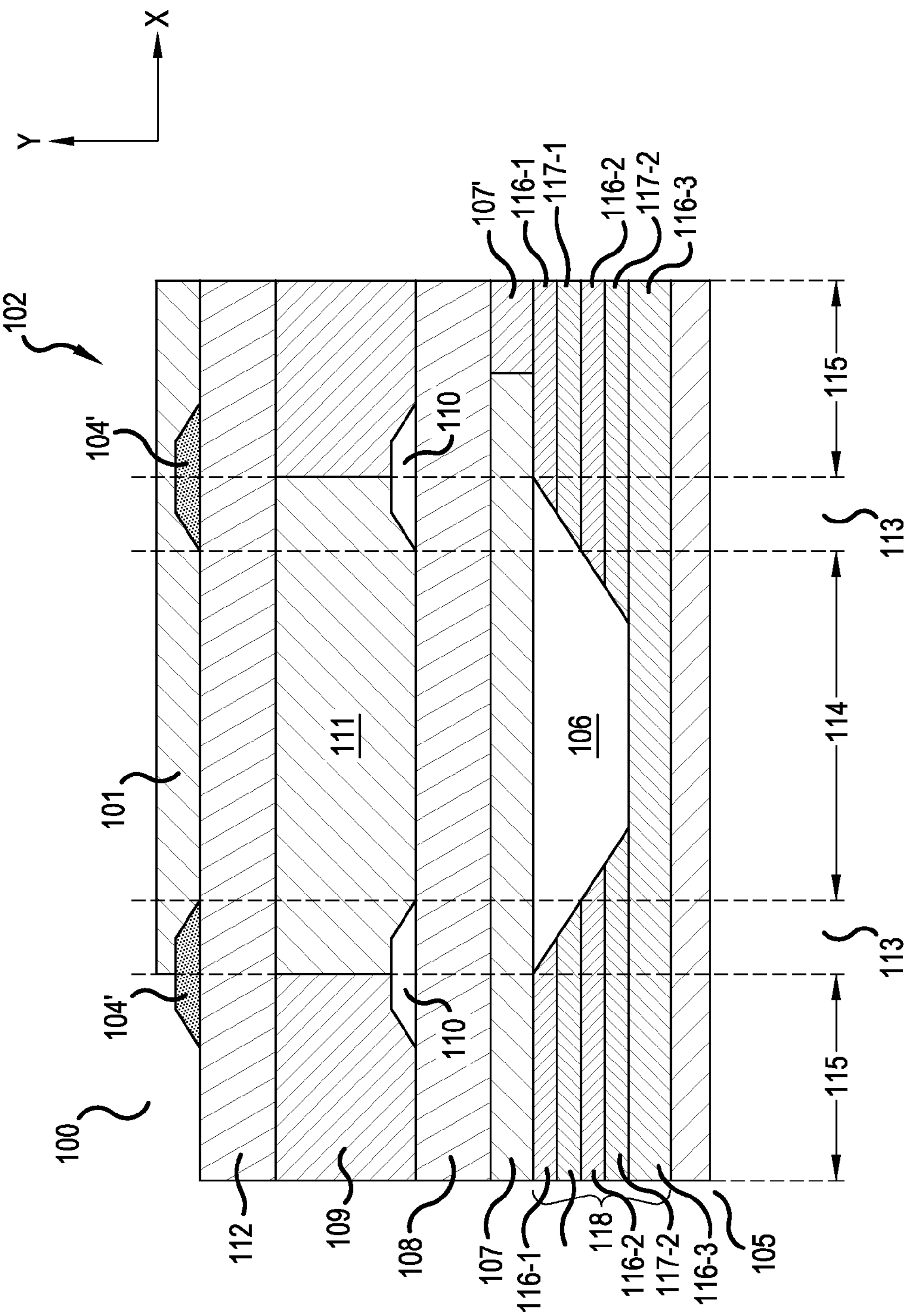
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107'
117-1
115
113
114

Fig. 1D

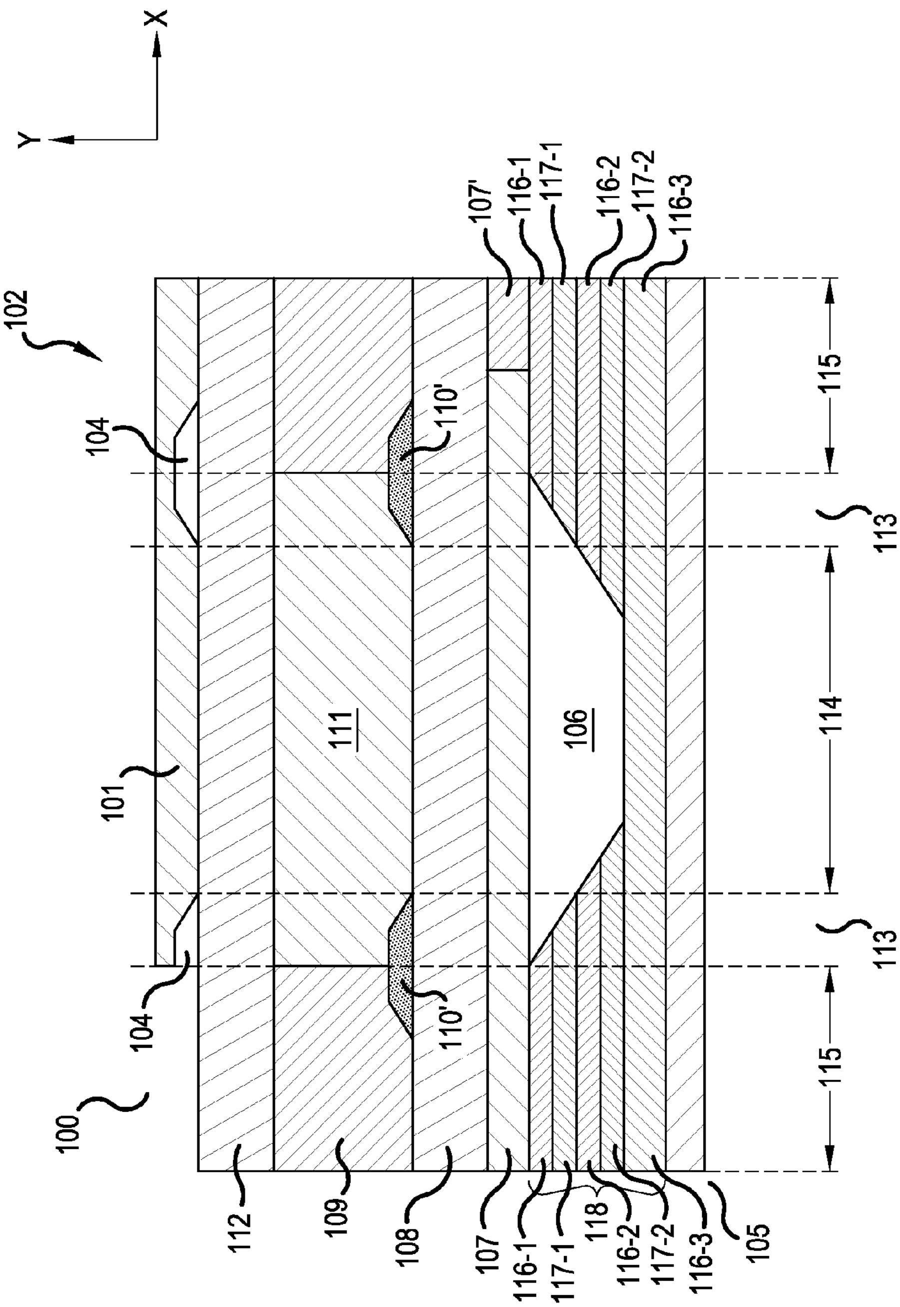

X
Y
102
104
110'
107'
116-1
117-1
116-2
117-2
116-3
115
113
114
111
106
101
100
112
109
108
107
118
105

Fig. 1E

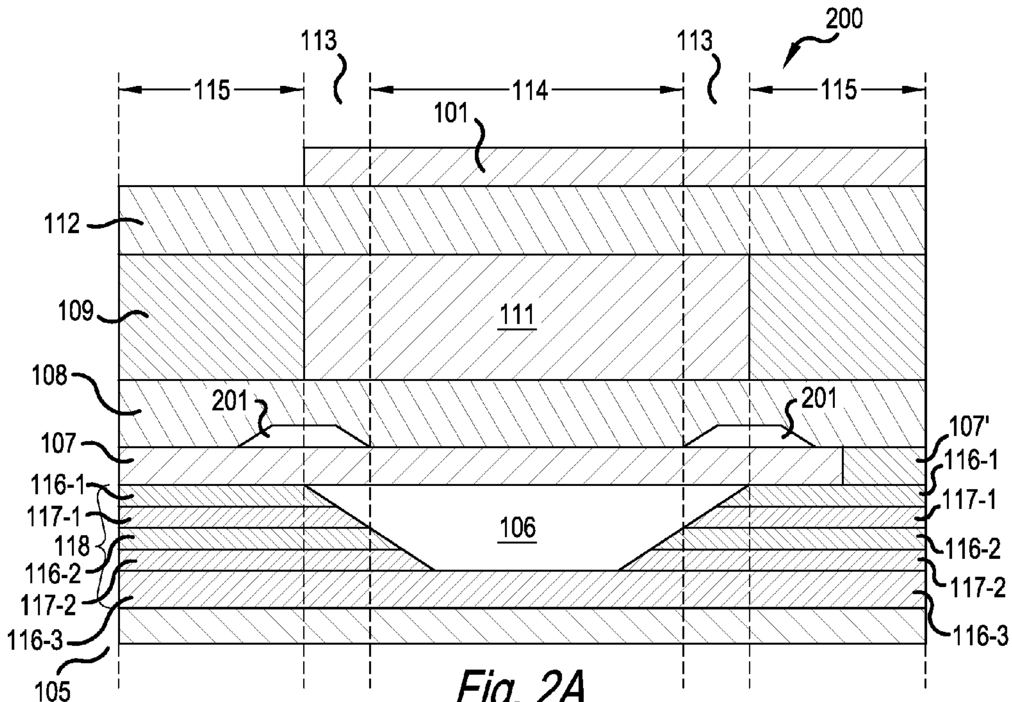

200
113
113
115
114
115
101
112
109
111
108
201
201
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 2A

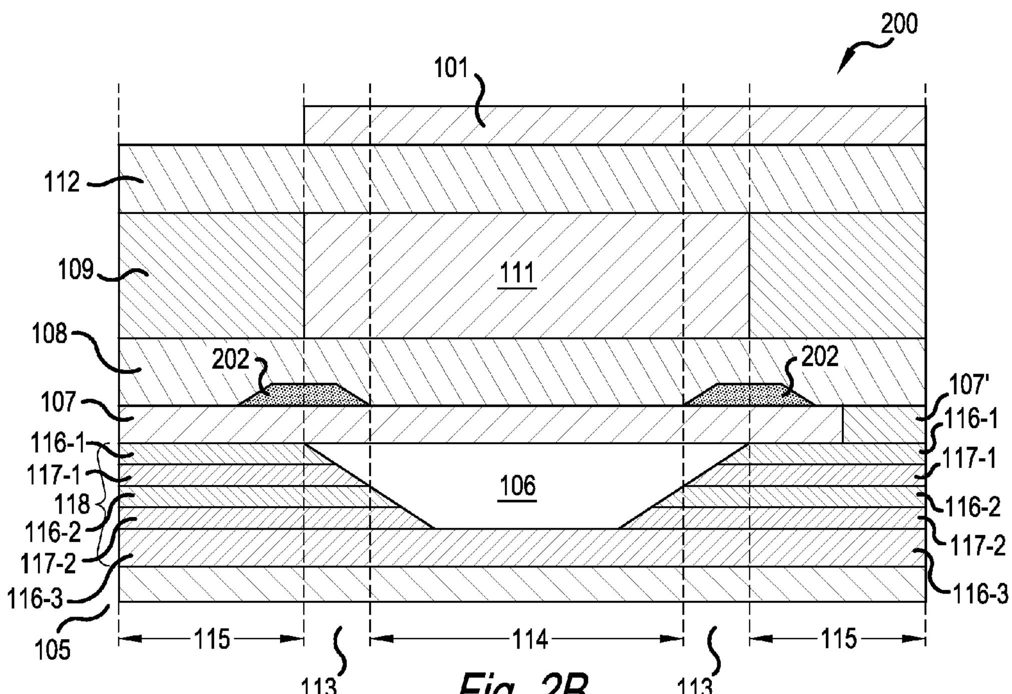

200
101
112
109
111
108
202
202
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105
115
114
115
113
113

Fig. 2B

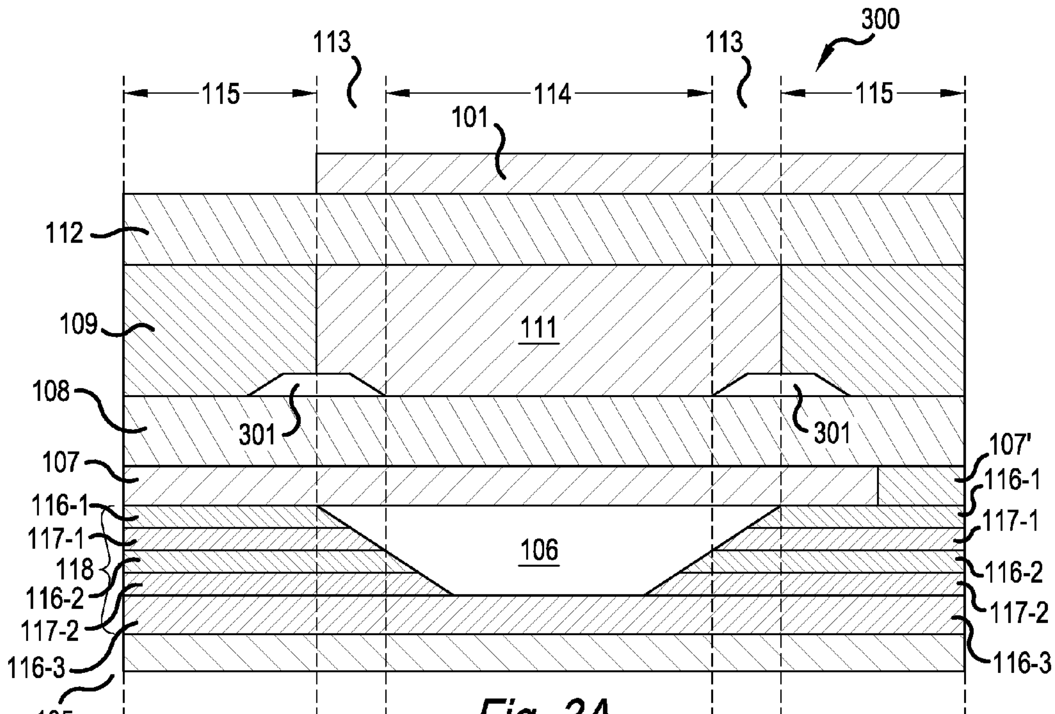

300
113
113
115
114
115
101
112
109
111
108
301
301
107
107'
116-1
116-1
117-1
117-1
118
116-2
116-2
117-2
117-2
116-3
116-3
106
105

Fig. 3A

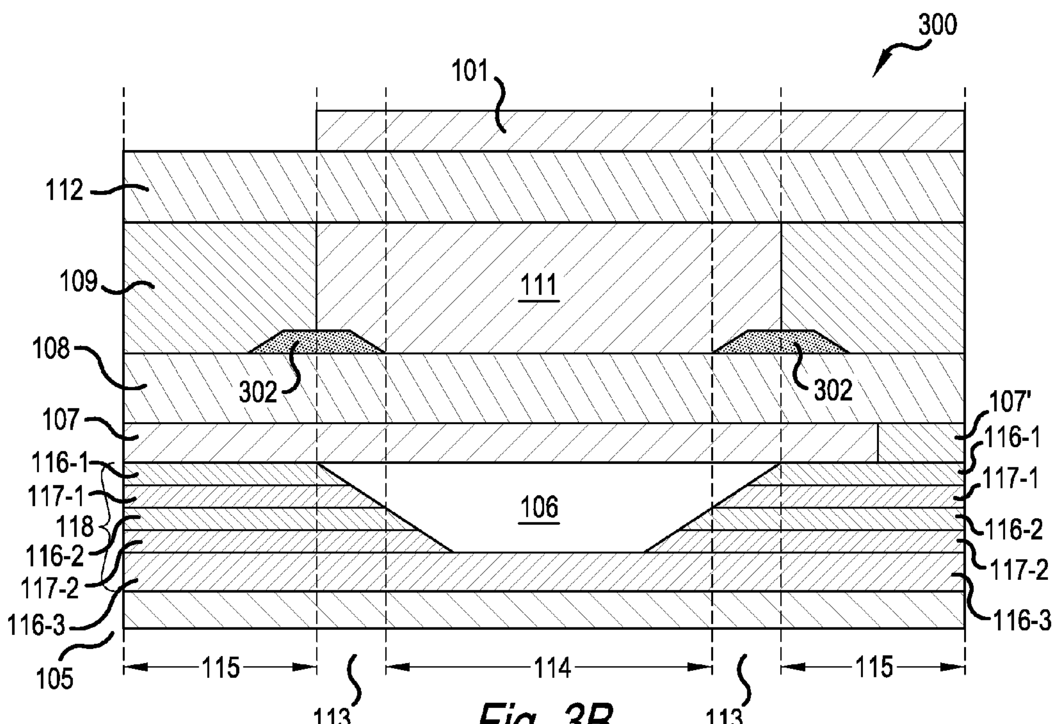

300
101
112
109
111
108
302
302
107
107'
116-1
116-1
117-1
117-1
118
116-2
116-2
117-2
117-2
116-3
116-3
106
105
115
114
115
113
113

Fig. 3B

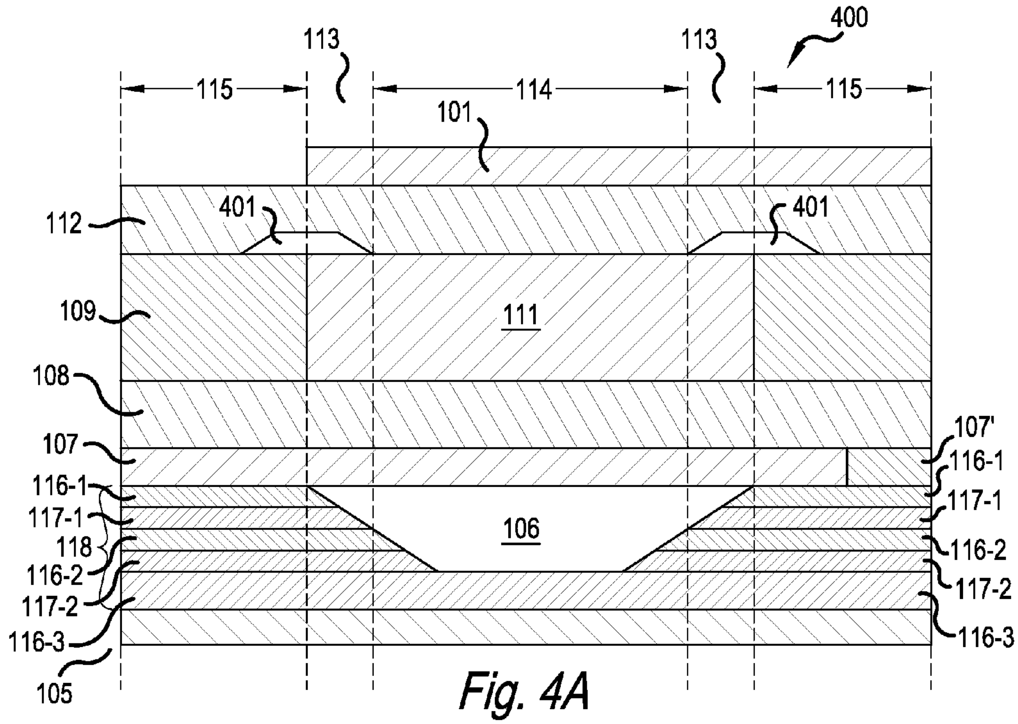

400
113
113
115
114
115
101
112
401
401
111
109
108
107
107'
116-1
116-1
117-1
117-1
106
118
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 4A

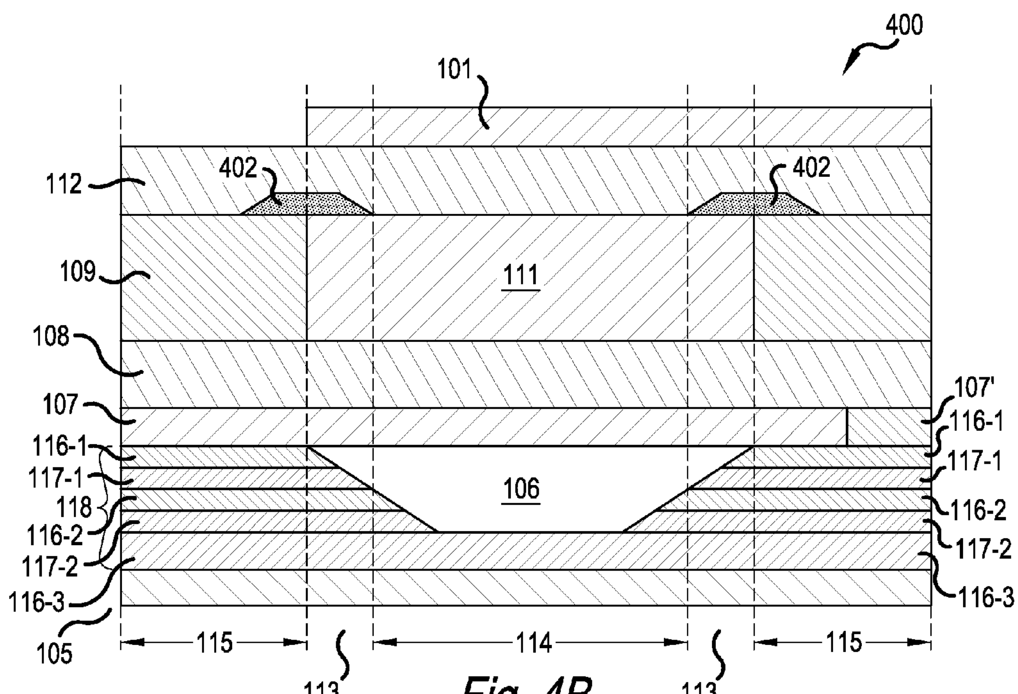

400
101
112
402
402
111
109
108
107
107'
116-1
116-1
117-1
117-1
106
118
116-2
116-2
117-2
117-2
116-3
116-3
105
115
114
115
113
113

Fig. 4B

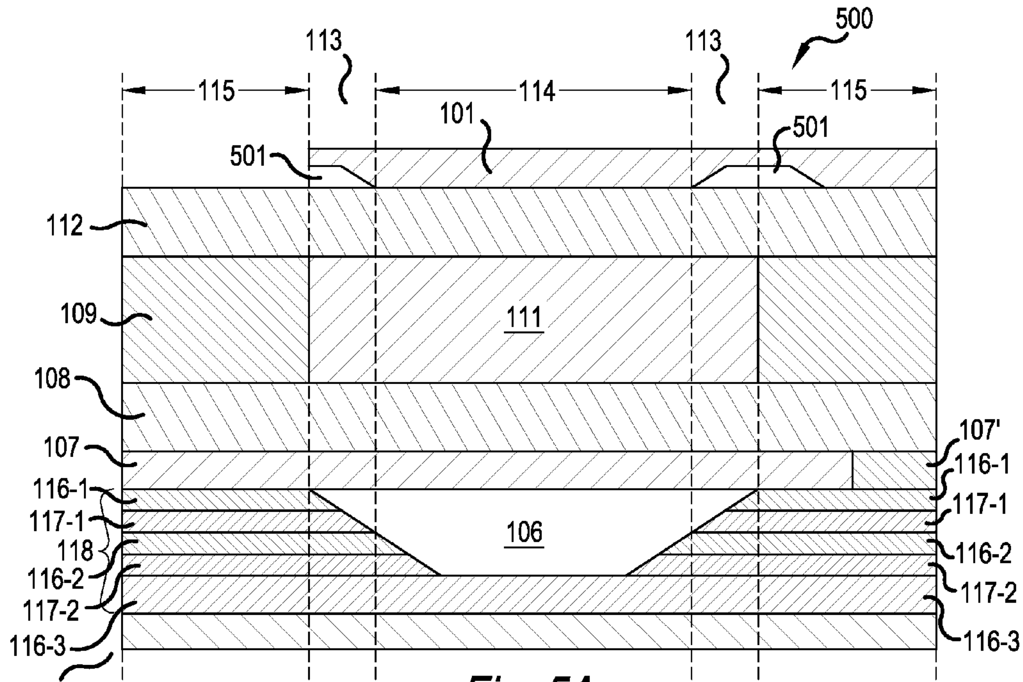

500
113
113
115
114
115
101
501
501
112
109
111
108
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 5A

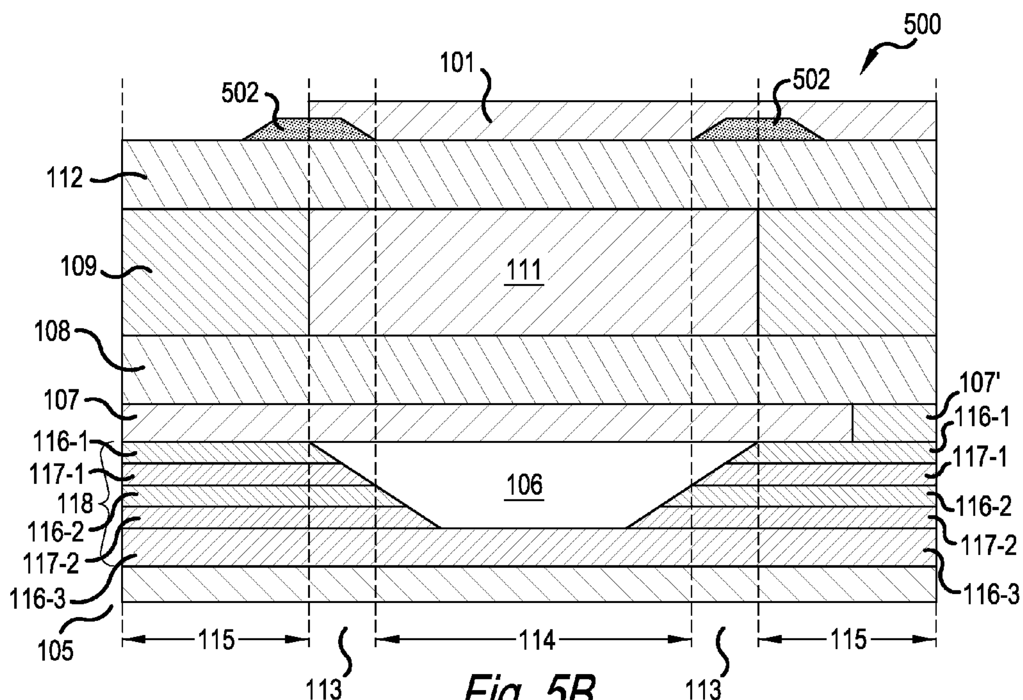

500
101
502
502
112
109
111
108
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105
115
114
115
113
113

Fig. 5B

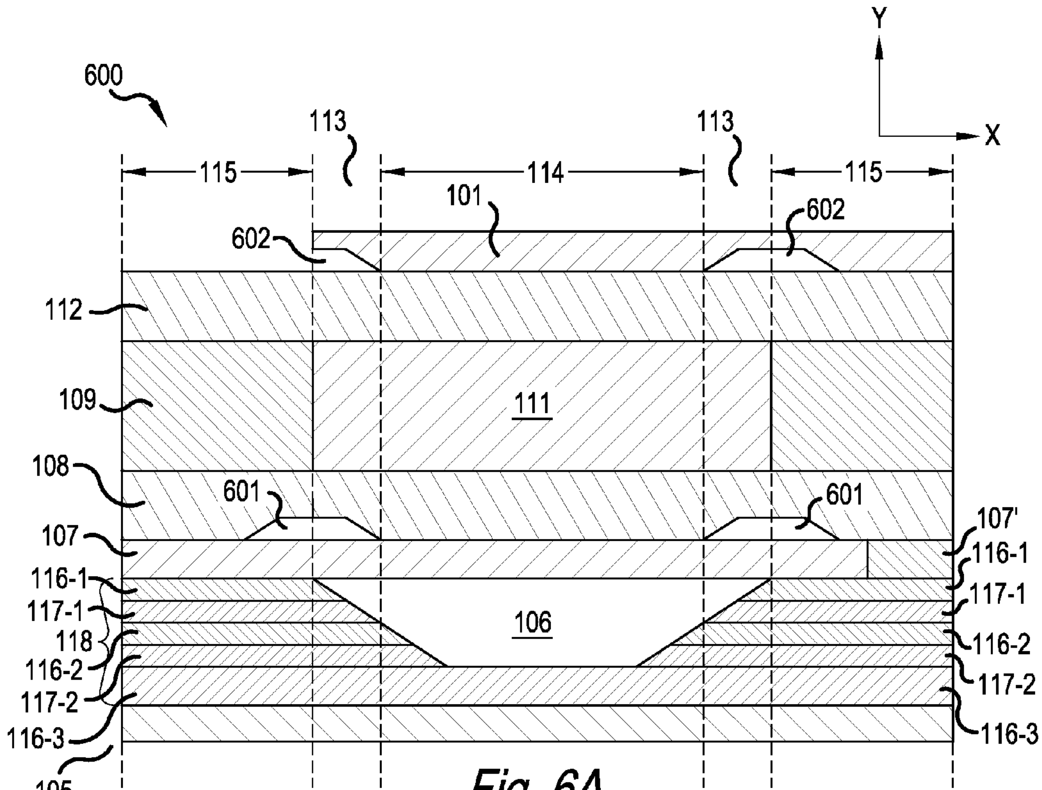

Y
X
600
113
113
115
114
115
101
602
602
112
109
111
108
601
601
107
107'
116-1
116-1
117-1
117-1
106
118
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 6A

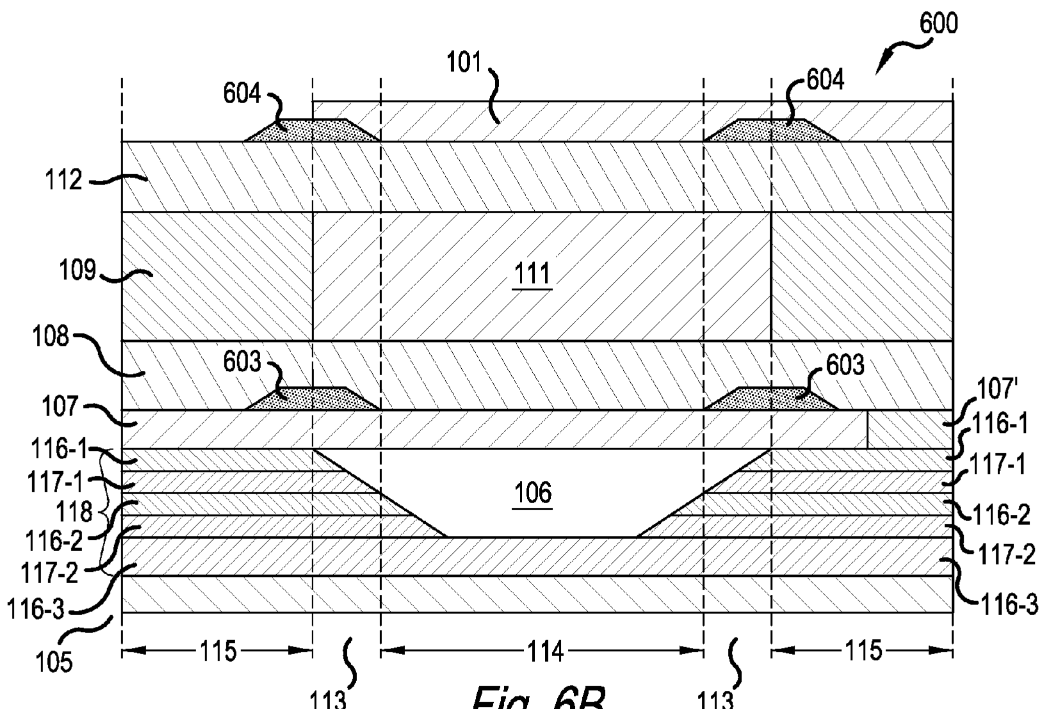

600
101
604
604
112
109
111
108
603
603
107
107'
116-1
116-1
117-1
117-1
106
118
116-2
116-2
117-2
117-2
116-3
116-3
105
115
114
115
113
113

Fig. 6B

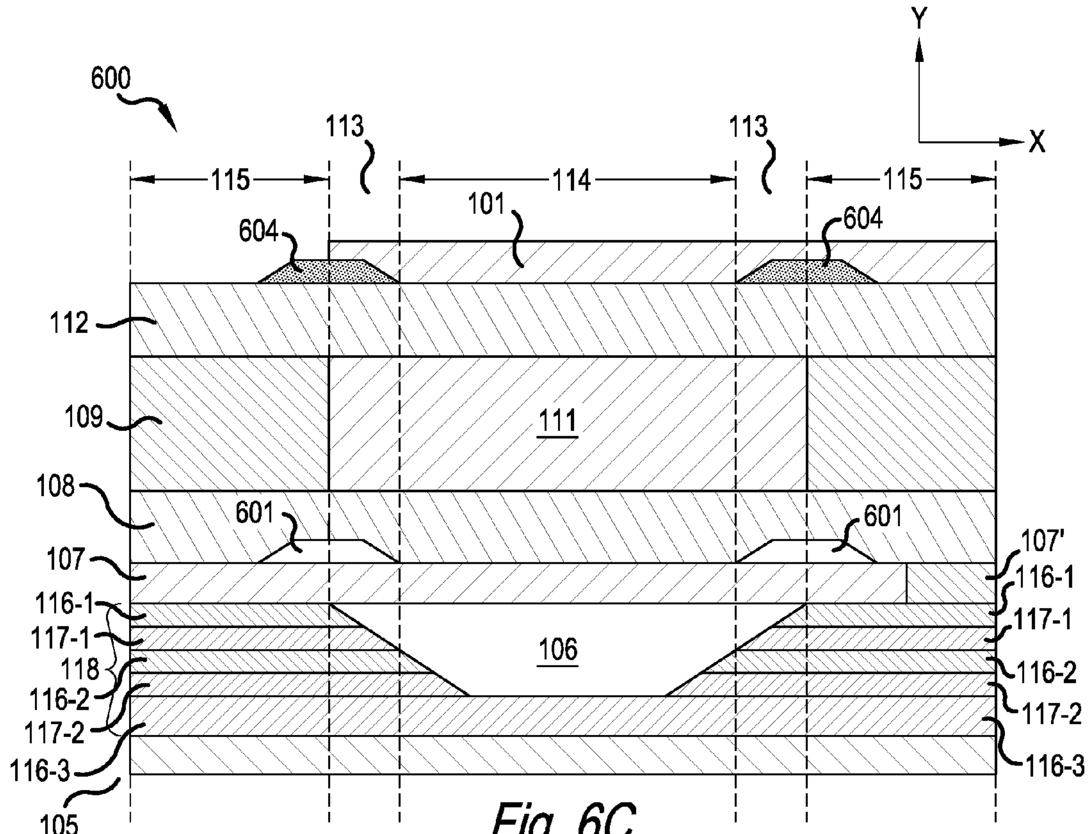

Y
X
600
113
113
115
114
115
101
604
604
112
109
111
108
601
601
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 6C

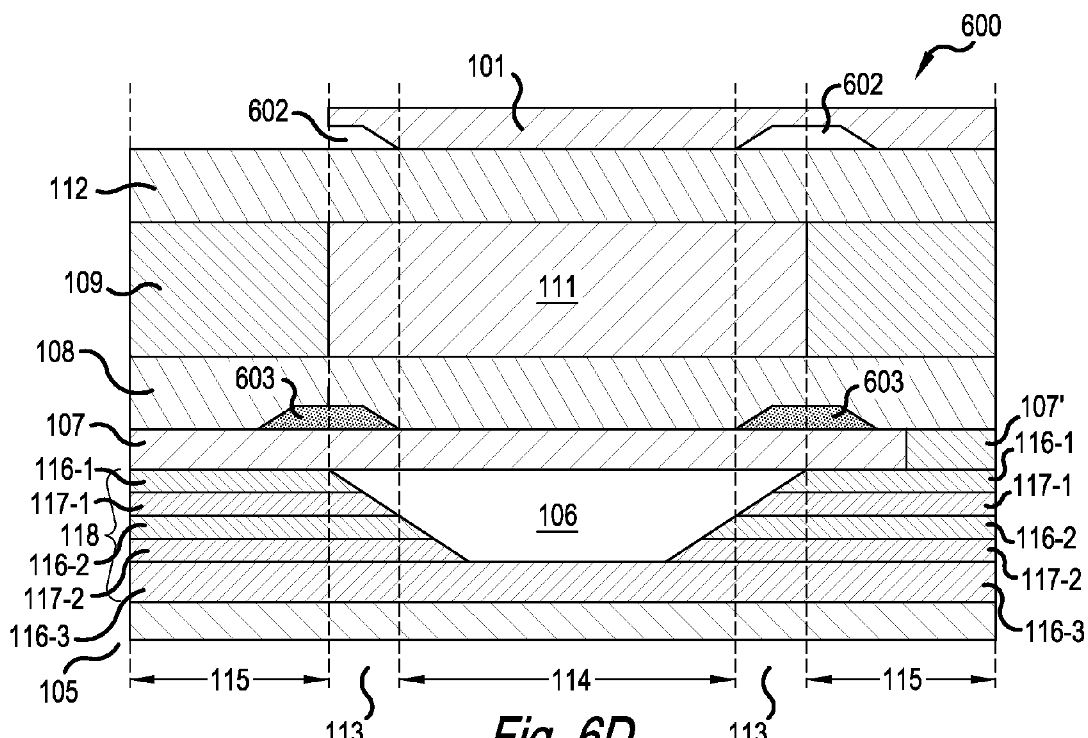
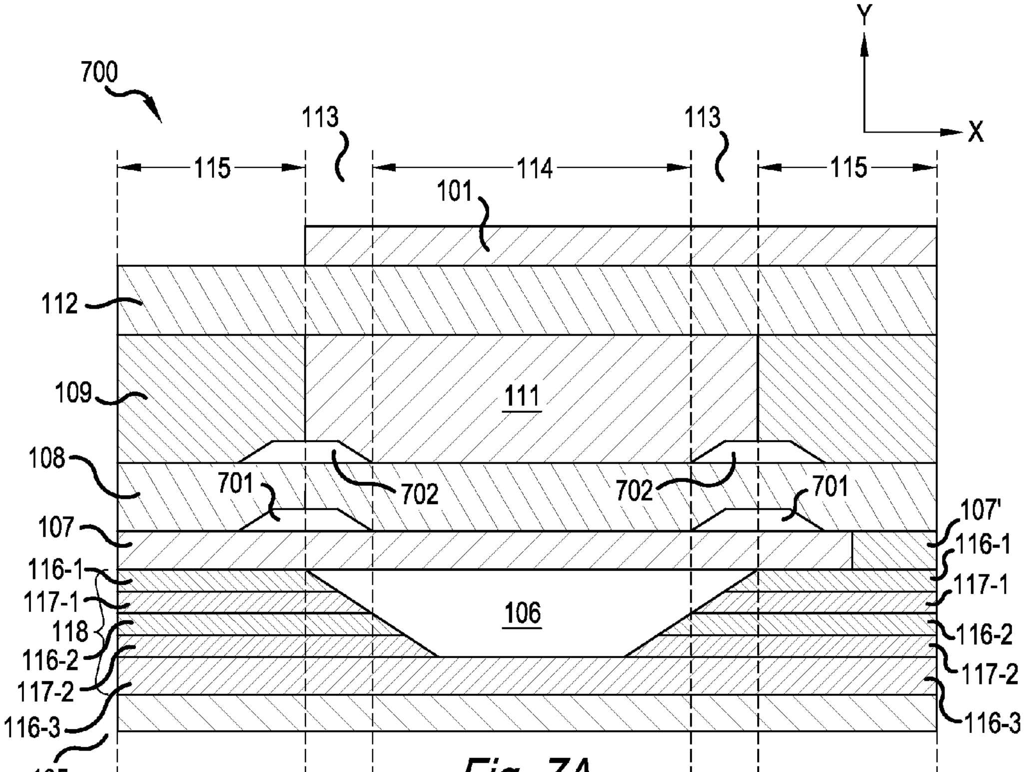
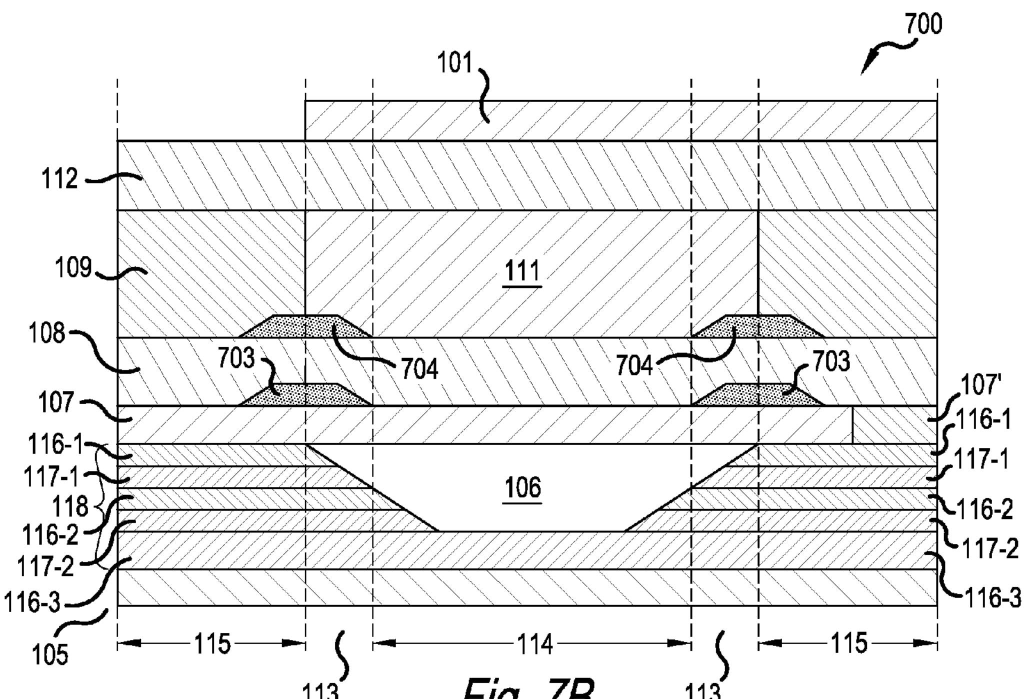

600
101
602
602
112
109
111
108
603
603
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105
115
114
115
113
113

Fig. 6D



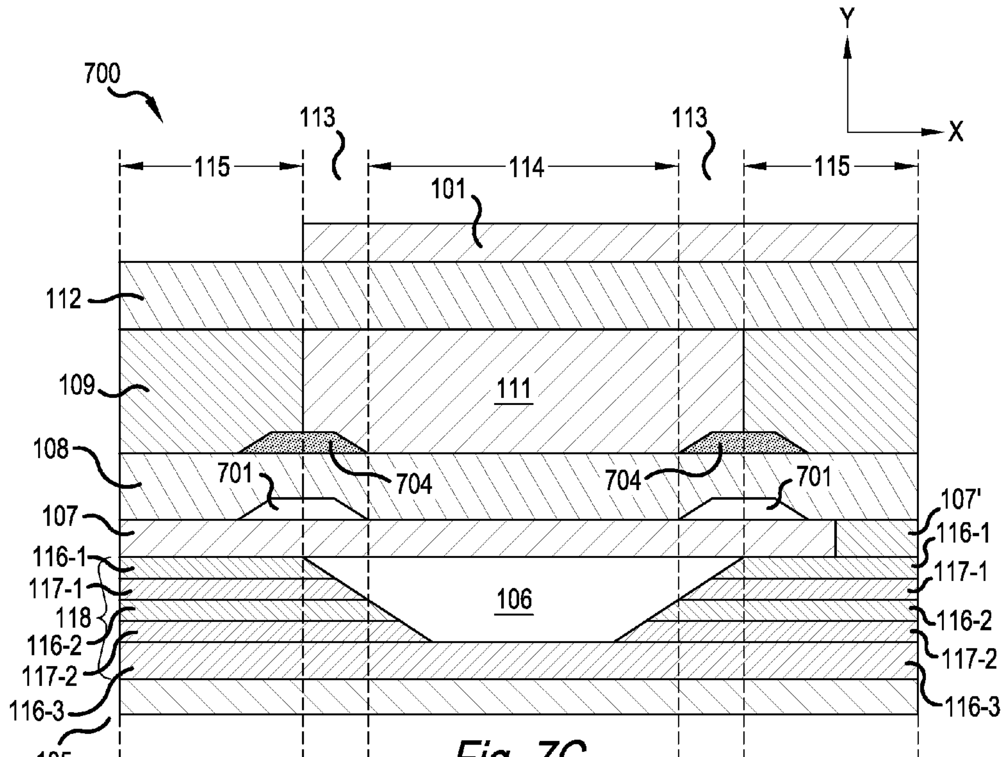
700
Y
X
113
113
115
114
115
101
112
109
111
108
701
702
702
701
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 7A



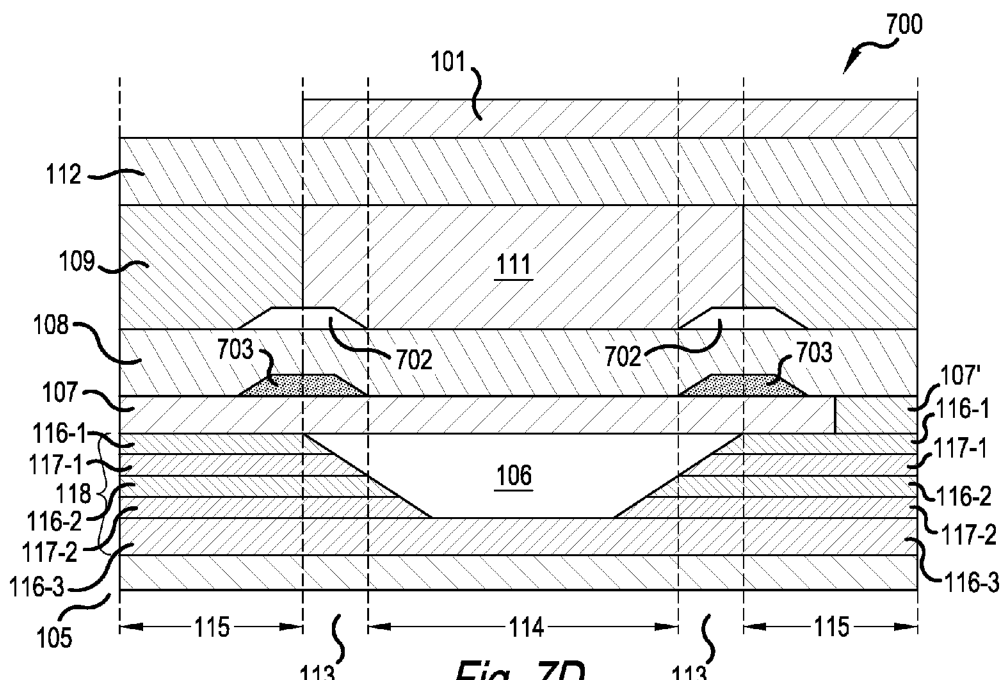
700
101
112
109
111
108
703
704
704
703
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105
115
114
115
113
113

Fig. 7B



700
113
113
Y
X
115
114
115
101
112
109
111
108
704
704
701
701
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 7C



700
101
112
109
111
108
702
702
703
703
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105
115
114
115
113
113

Fig. 7D

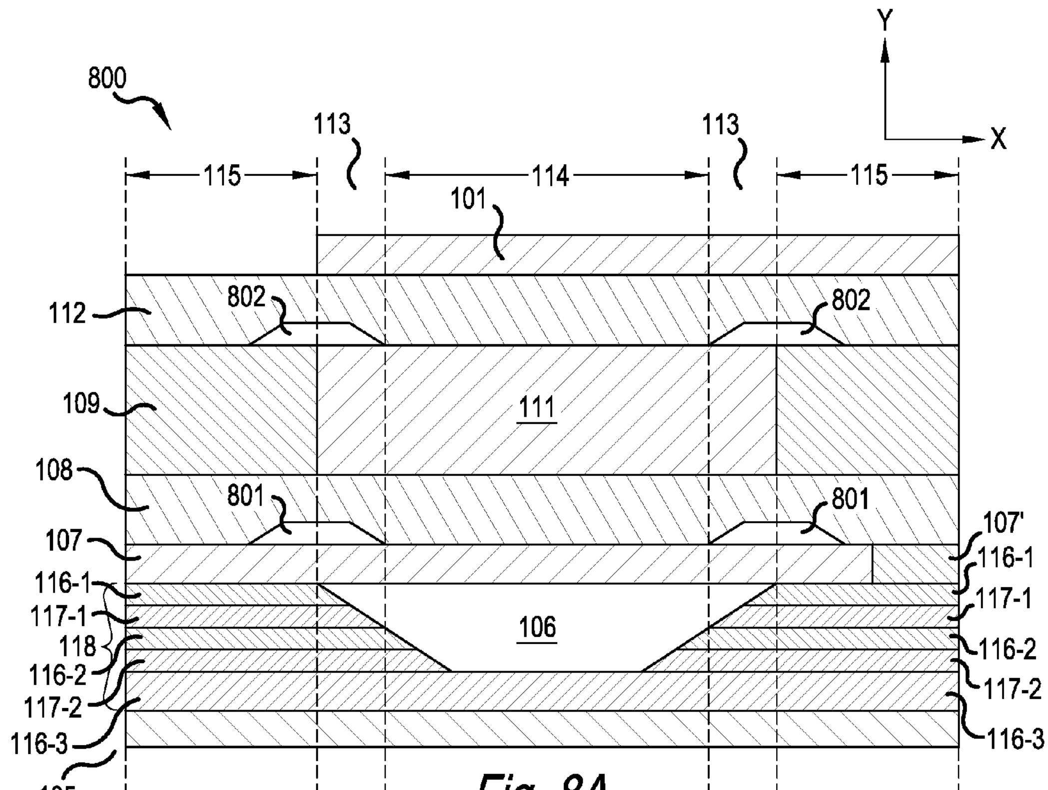

800
Y
X
113
113
115
114
115
101
112
802
802
109
111
108
801
801
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 8A

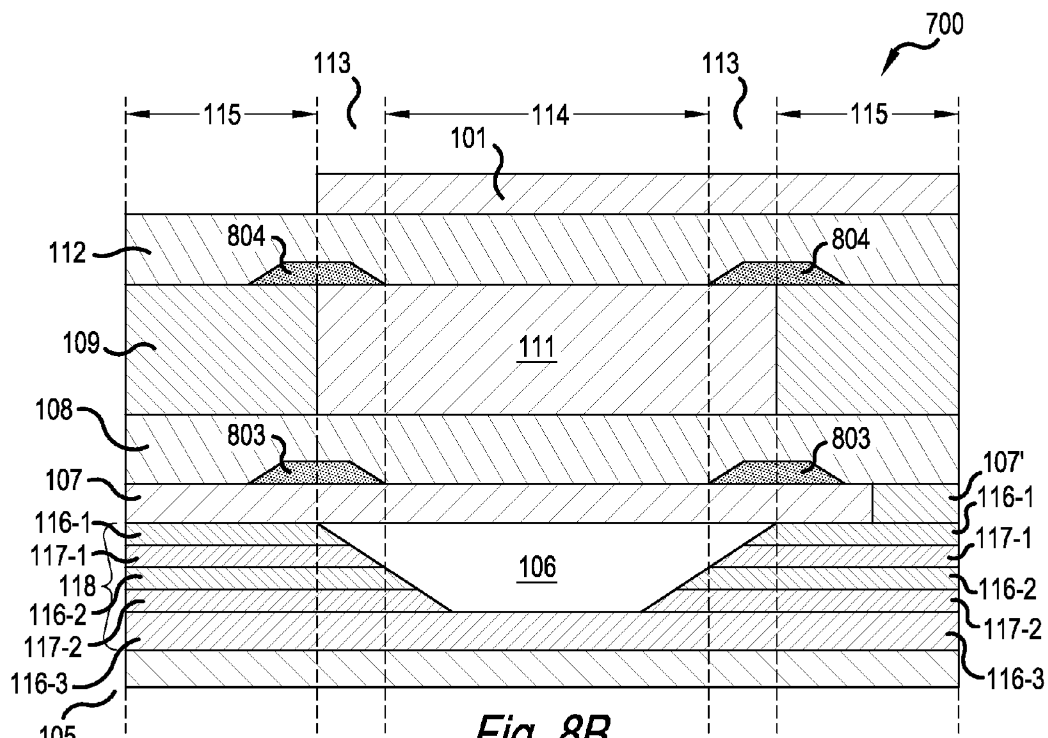
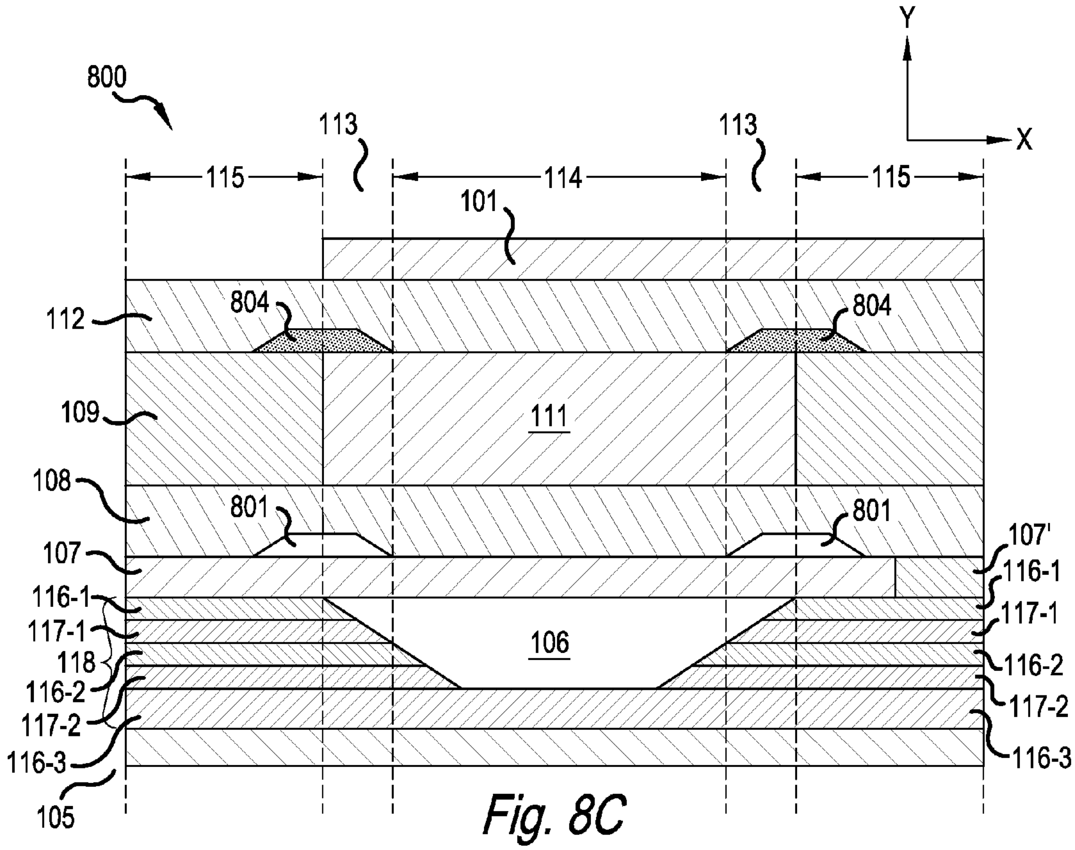
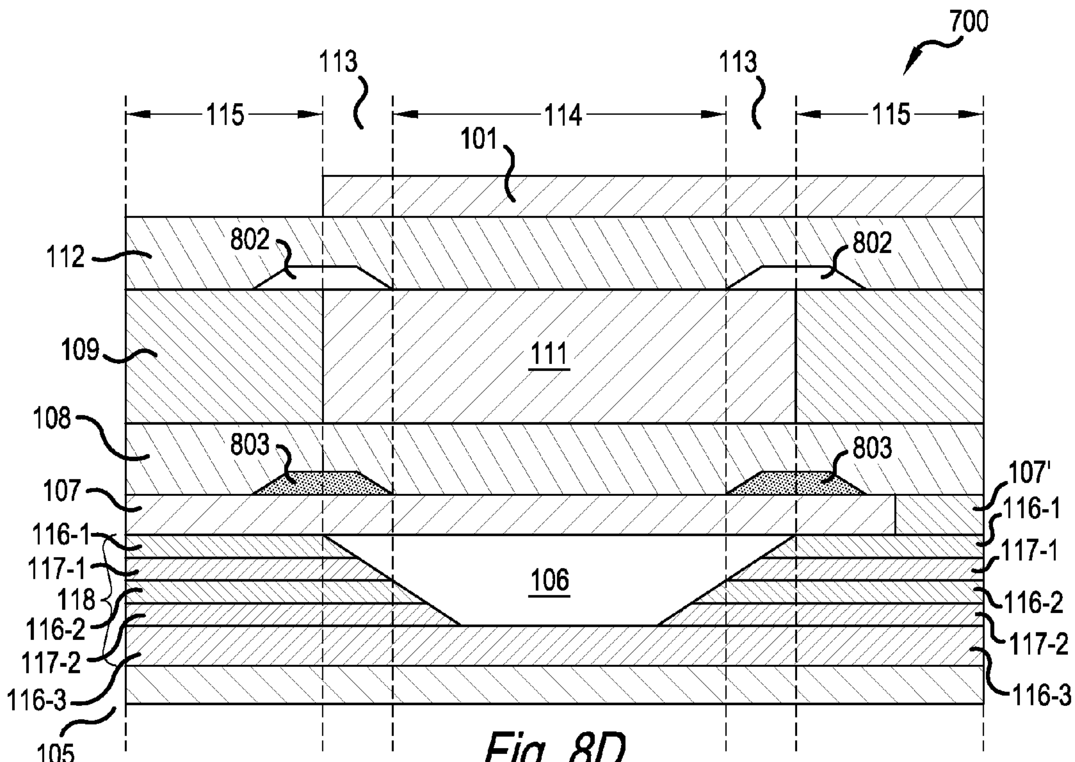

700
113
113
115
114
115
101
112
804
804
109
111
108
803
803
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 8B



800
Y
X
113
113
115
114
115
101
112
804
804
109
111
108
801
801
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 8C



700
113
113
115
114
115
101
112
802
802
109
111
108
803
803
107
107'
116-1
116-1
117-1
117-1
118
106
116-2
116-2
117-2
117-2
116-3
116-3
105

Fig. 8D

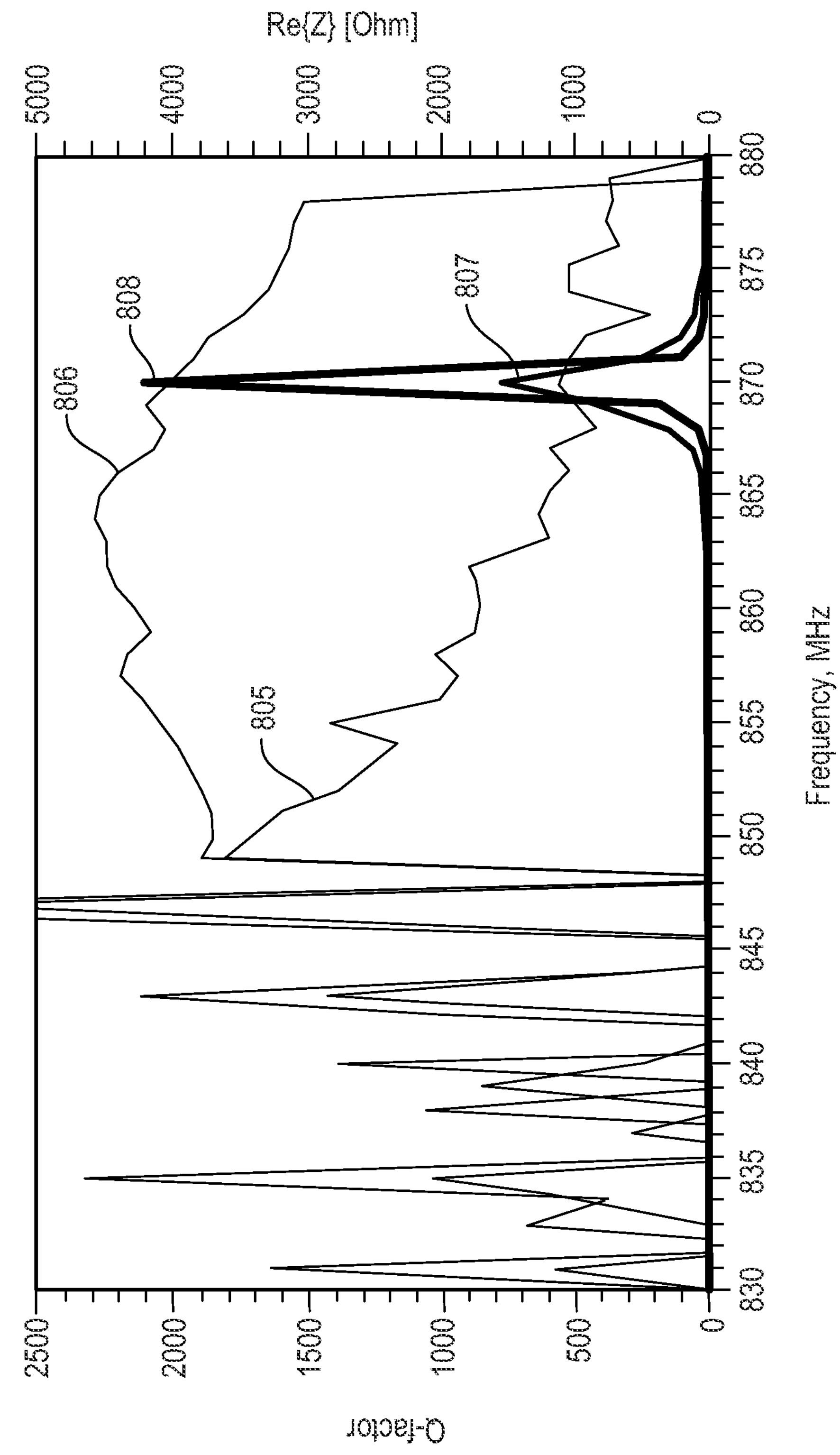
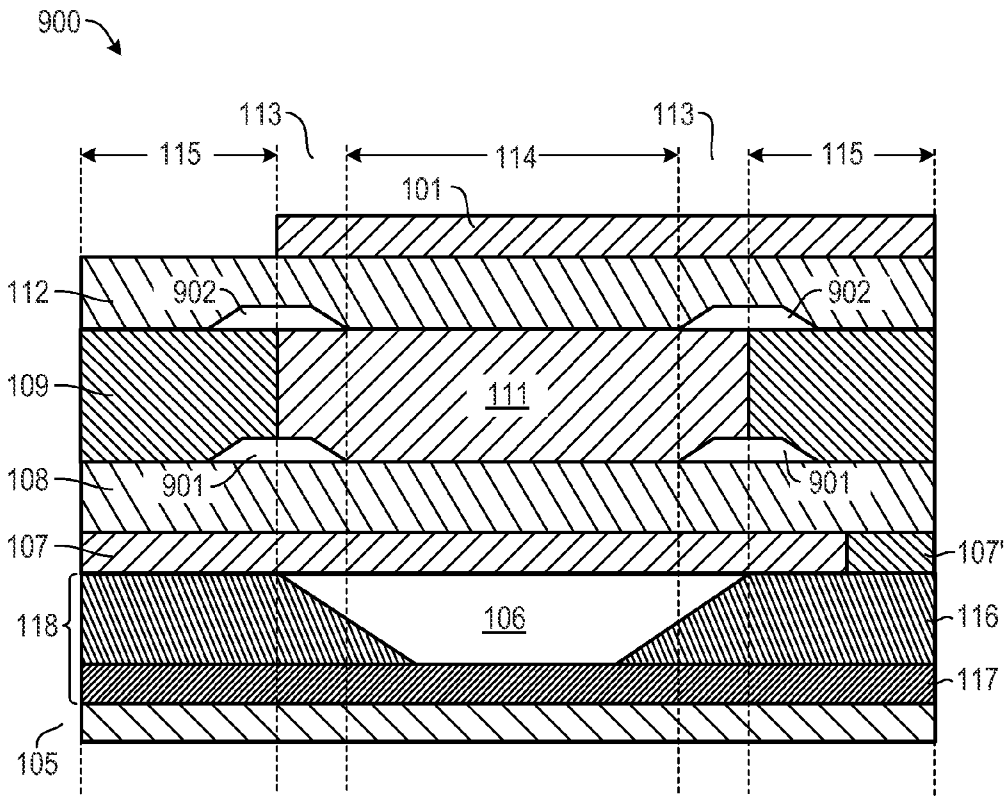
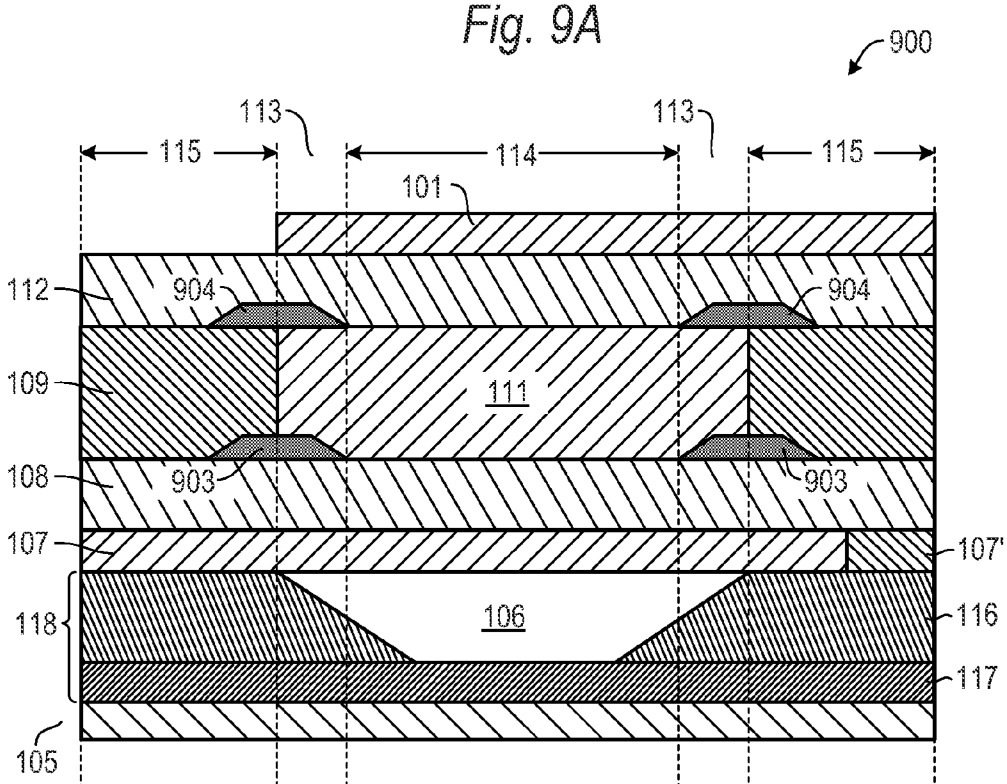

Re{Z} [Ohm]
5000
4000
3000
2000
1000
0
Q-factor
2500
2000
1500
1000
500
0
830
835
840
845
850
855
860
865
870
875
880
Frequency, MHz
805
806
807
808

Fig. 8E



900
113
113
115
114
115
101
112
902
902
109
111
108
901
901
107
107'
118
106
116
117
105

Fig. 9A



900
113
113
115
114
115
101
112
904
904
109
111
108
903
903
107
107'
118
106
116
117
105

Fig. 9B

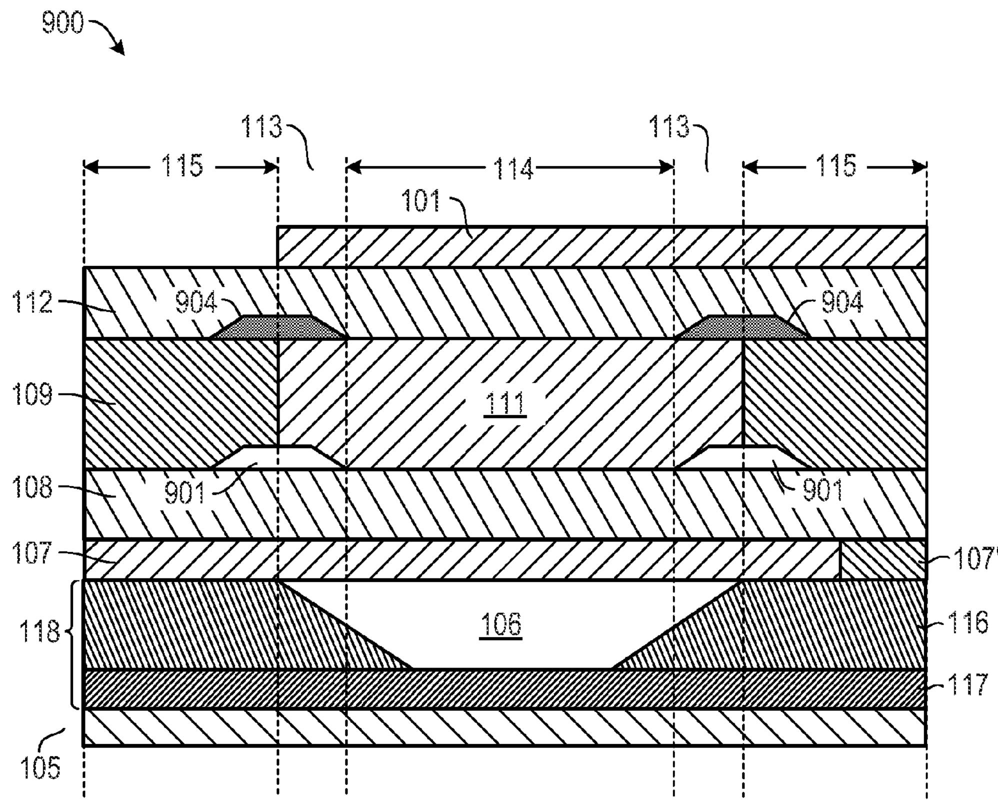

900
113
113
115
114
115
101
112
904
904
109
111
108
901
901
107
107'
118
106
116
117
105

Fig. 9C

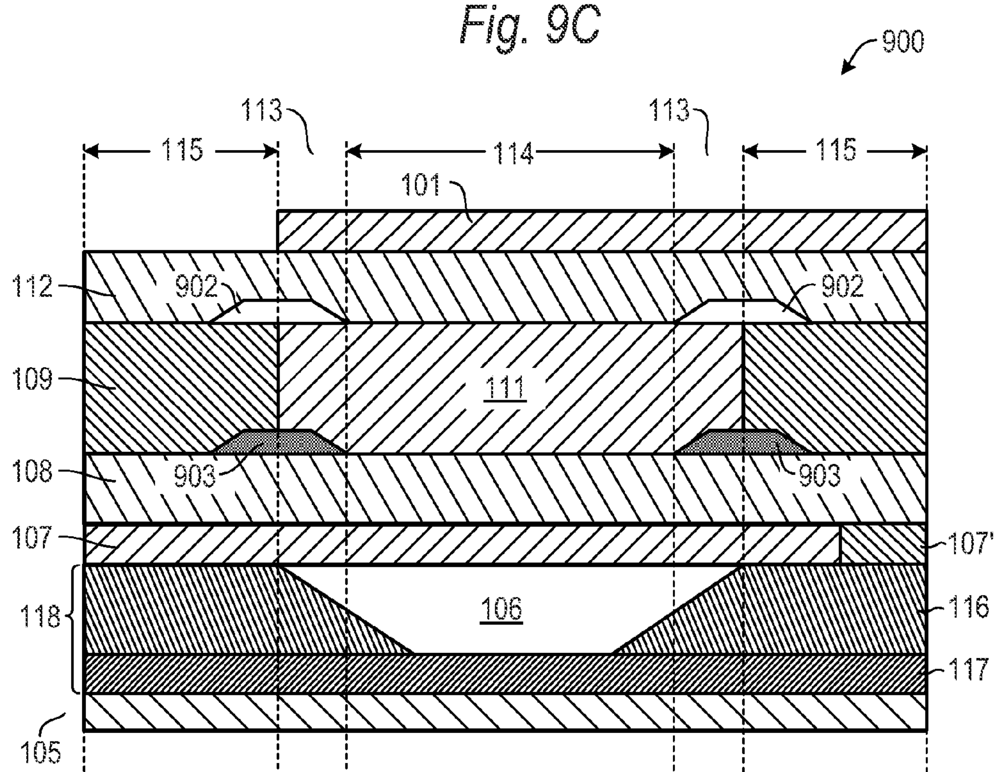

900
113
113
115
114
115
101
112
902
902
109
111
108
903
903
107
107'
118
106
116
117
105

Fig. 9D

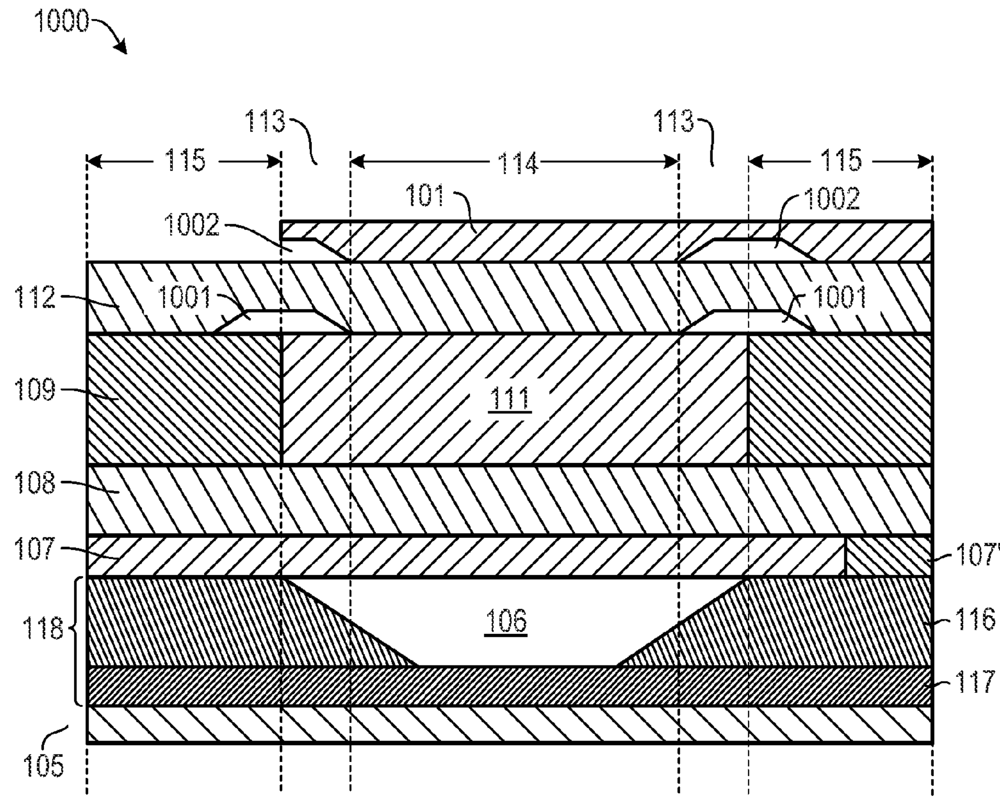


Fig. 10A

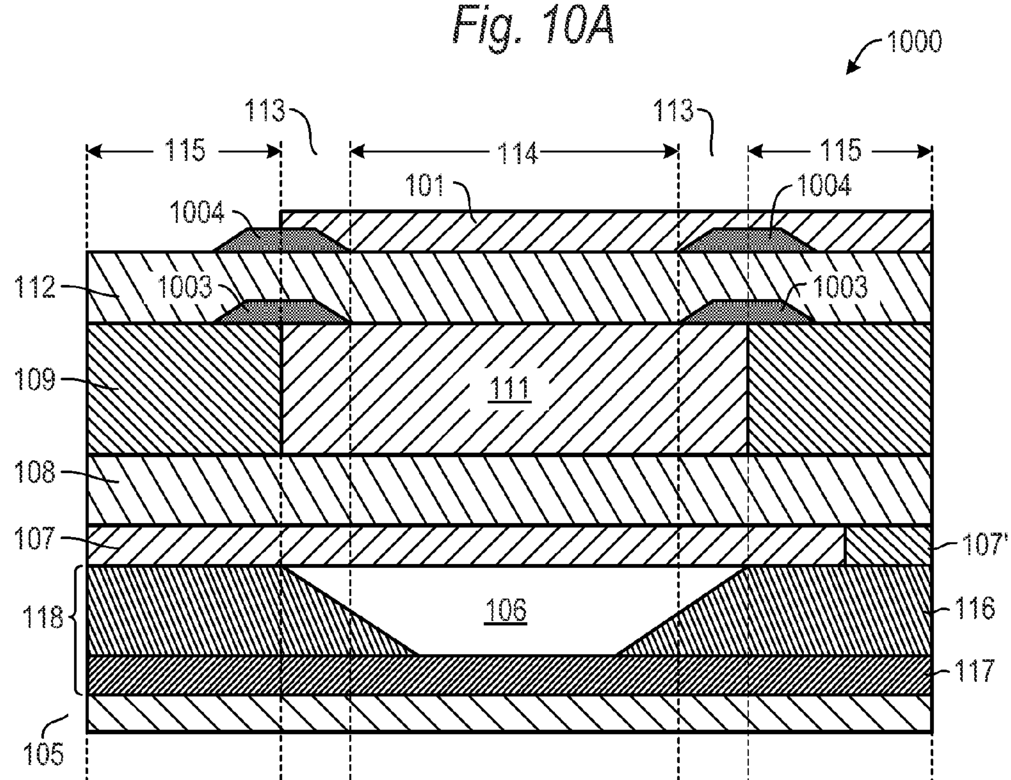


Fig. 10B

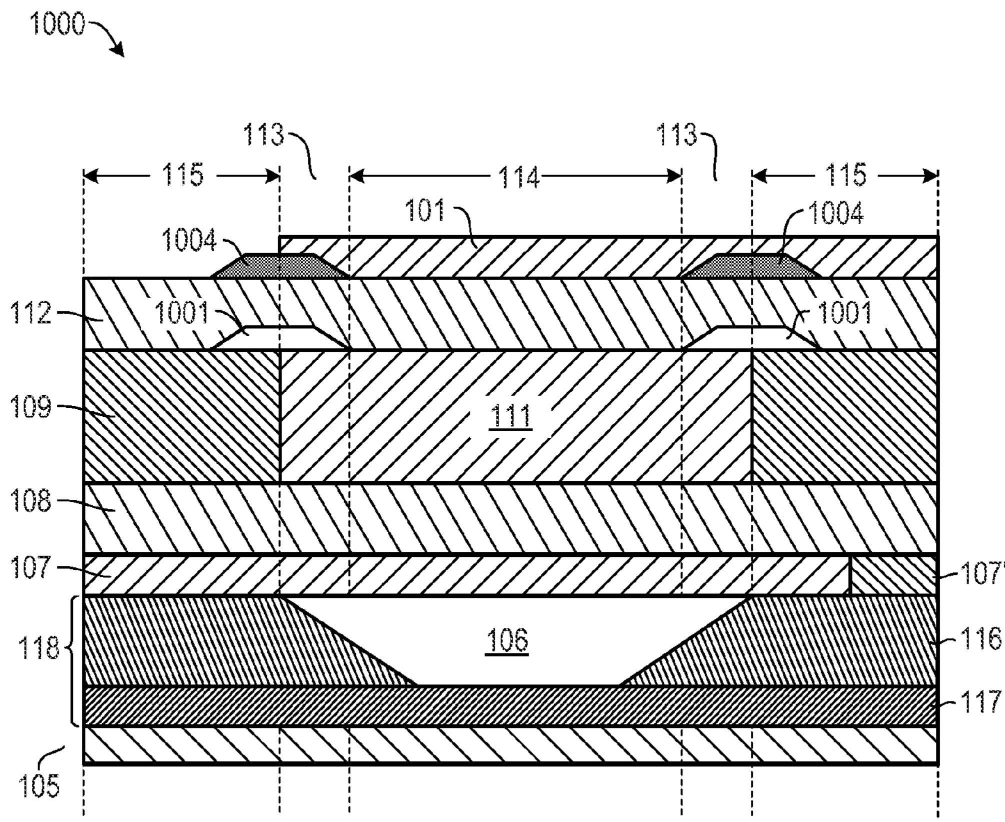


Fig. 10C

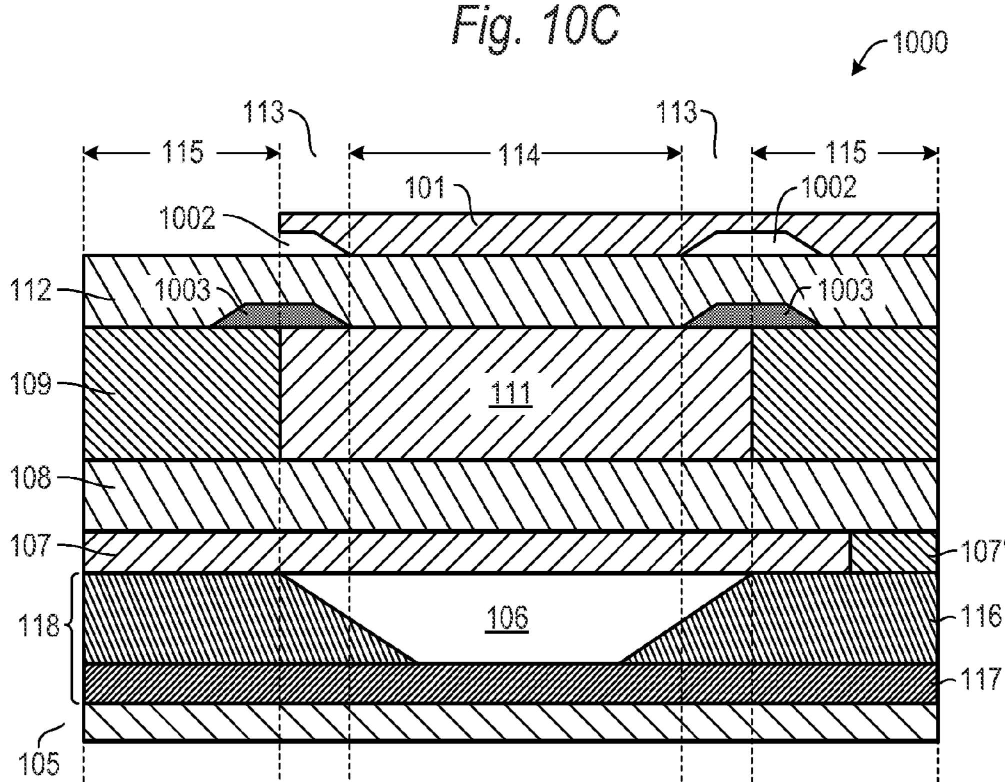


Fig. 10D

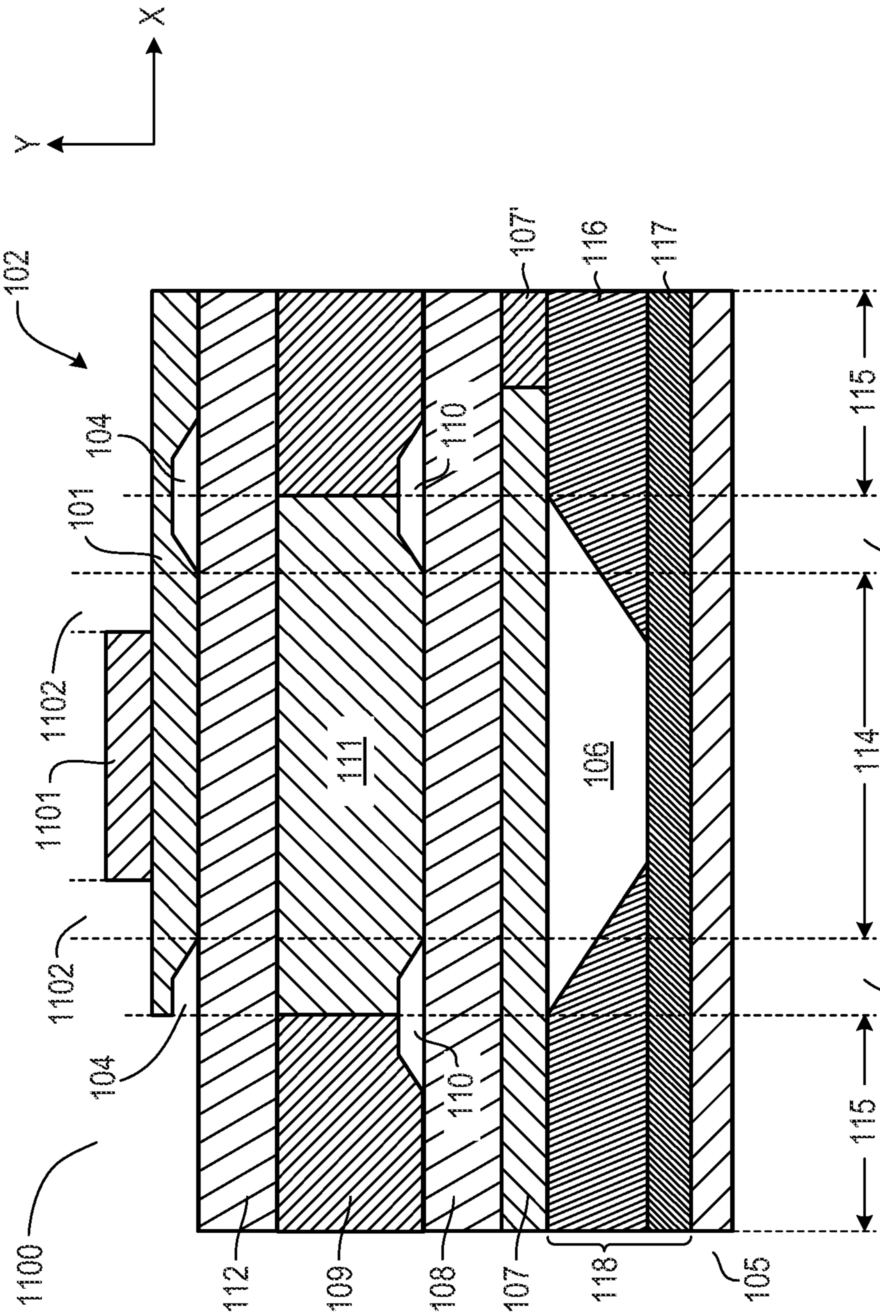

X
Y
102
104
101
1102
1101
1102
104
1100
110
111
110
107'
116
117
106
115
113
114
113
115
112
109
108
107
118
105

Fig. 11A

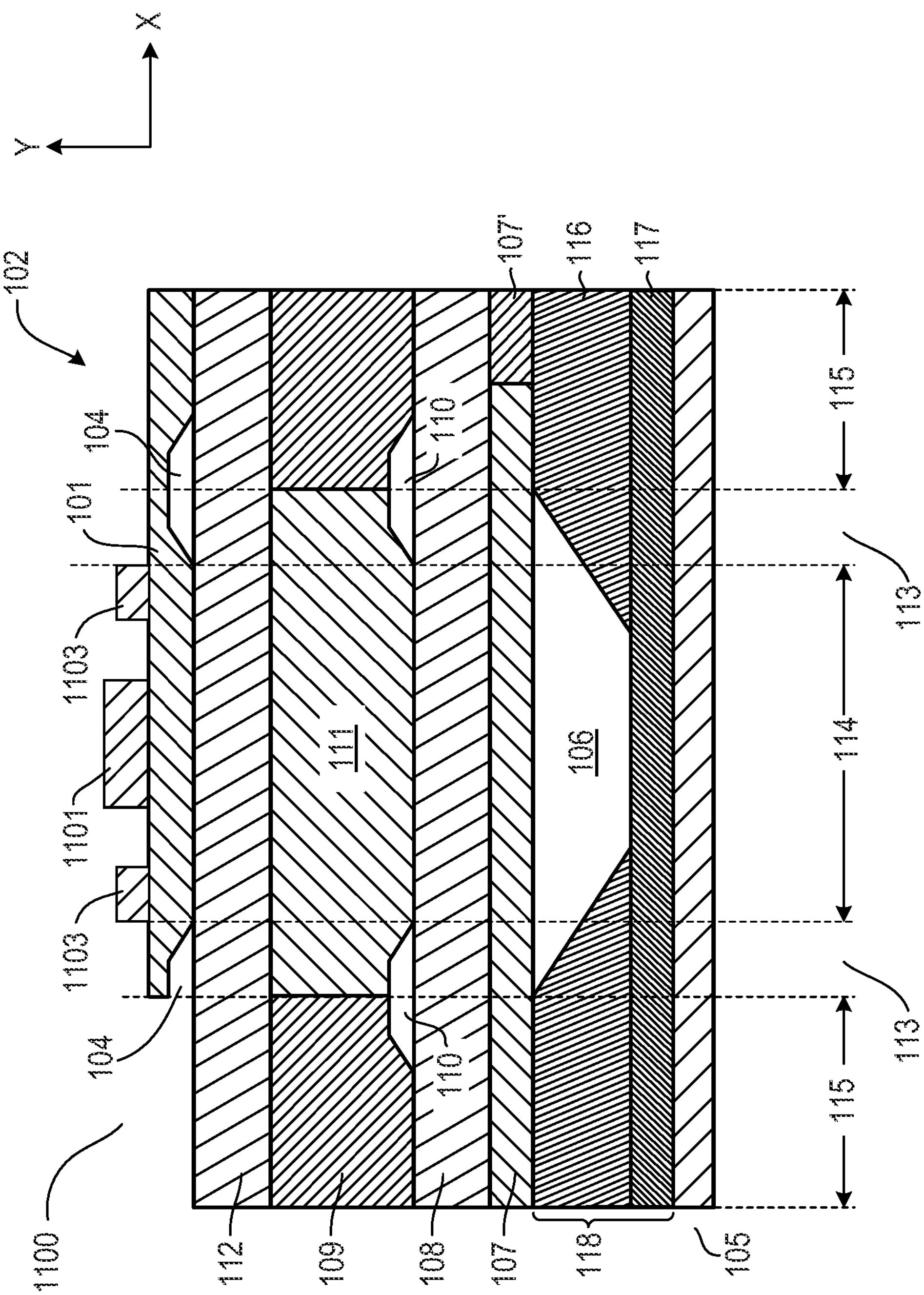

X
Y
102
104
101
1103
1101
1103
104
1100
112
109
108
107
118
105
107'
116
117
115
110
111
106
114
113
110
115
113

Fig. 11B

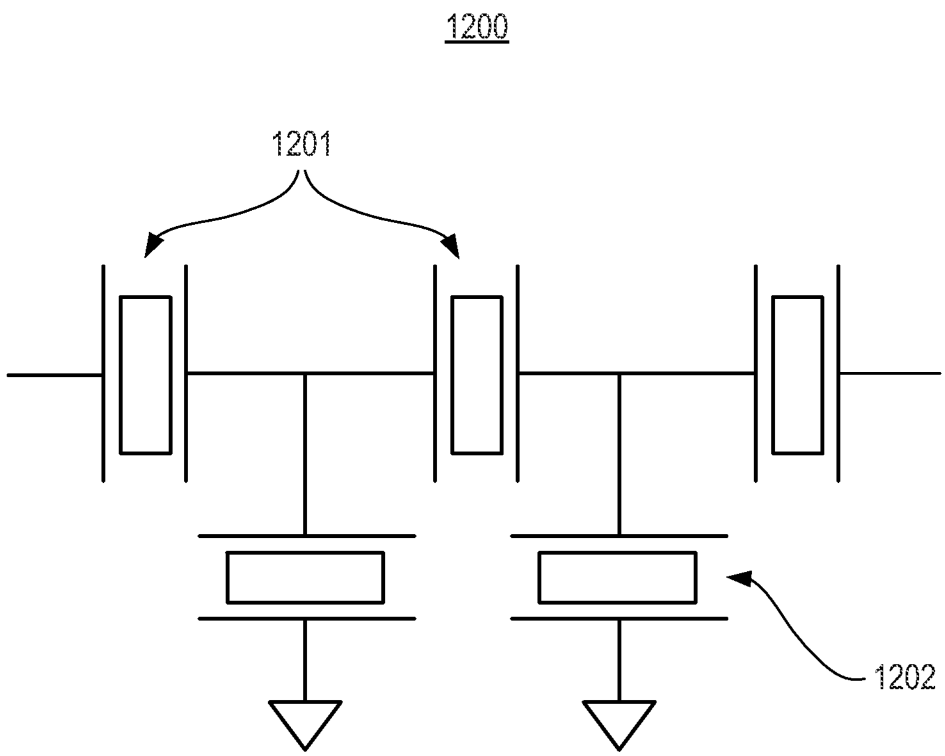


Fig. 12

STACKED BULK ACOUSTIC RESONATOR COMPRISING A BRIDGE AND AN ACOUSTIC REFLECTOR ALONG A PERIMETER OF THE RESONATOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part application of commonly owned U.S. patent application Ser. No. 13/074,262 entitled "Stacked Acoustic Resonator Comprising Bridge" filed on Mar. 29, 2011 to Dariusz Burak, et al. The present application claims priority under 35 U.S.C. §120 to U.S. patent application Ser. No. 13/074,262, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND

Transducers generally convert electrical signals to mechanical signals or vibrations, and/or mechanical signals or vibrations to electrical signals. Acoustic transducers, in particular, convert electrical signals to acoustic signals (sound waves) in a transmit mode and/or convert received acoustic waves to electrical signals in a receive mode. Acoustic transducers generally include acoustic resonators, such as thin film bulk acoustic resonators (FBARs), surface acoustic wave (SAW) resonators or bulk acoustic wave (BAW) resonators, and may be used in a wide variety of electronic applications, such as cellular telephones, personal digital assistants (PDAs), electronic gaming devices, laptop computers and other portable communications devices. For example, FBARs may be used for electrical filters and voltage transformers. Generally, an acoustic resonator has a layer of piezoelectric material between two conductive plates (electrodes), which may be formed on a thin membrane. FBAR devices, in particular, generate laterally propagating acoustic waves when stimulated by an applied time-varying electric field confined to finite-sized electrodes, as well as higher order harmonic mixing products. The lateral modes and the higher order harmonic mixing products may have a deleterious impact on functionality.

A stacked bulk acoustic resonator (SBAR), also referred to as a double bulk acoustic resonator (DBAR), includes two layers of piezoelectric materials between three electrodes in a single stack, forming a single resonant cavity. That is, a first layer of piezoelectric material is formed between a first (bottom) electrode and a second (middle) electrode, and a second layer of piezoelectric material is formed between the second (middle) electrode and a third (top) electrode. Generally, the stacked bulk acoustic resonator device allows reduction of the area of a single bulk acoustic resonator device by about half.

In FBAR devices, mitigation of acoustic losses at the boundaries and the resultant mode confinement in the active region of the FBAR (the region of overlap of the top electrode, the piezoelectric layer, and the bottom electrode) has been effected through various methods. Notably, frames are provided along one or more sides of the FBARs. The frames create an acoustic impedance mismatch that reduces losses by reflecting desired modes back to the active area of the resonator, thus improving the confinement of desired modes within the active region of the FBAR and minimizing conversion of these modes at the edges of the electrodes into unwanted modes that cannot couple back to electric field (like shear and flexural modes).

While the incorporation of frames has resulted in improved mode confinement and attendant improvement in the quality (Q) factor of the FBAR, direct application of known frame elements has not resulted in significant improvement in mode confinement and Q of known DBARs.

What is needed, therefore, is a DBAR that overcomes at least the known shortcomings described above.

BRIEF DESCRIPTION OF THE DRAWINGS

The illustrative embodiments are best understood from the following detailed description when read with the accompanying drawing figures. It is emphasized that the various features are not necessarily drawn to scale. In fact, the dimensions may be arbitrarily increased or decreased for clarity of discussion. Wherever applicable and practical, like reference numerals refer to like elements.

FIG. **1**A is a top view of a DBAR in accordance with a representative embodiment.

FIGS. **1**B~**1**E are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **2**B~**2**B are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **3**A~**3**B are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **4**A~**4**B are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **5**A~**5**B are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **6**A~**6**D are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **7**A~**7**D are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **8**A~**8**D are cross-sectional views of DBARs in accordance with a representative embodiment.

FIG. **8**E is a graphical representation of the Q factor of an odd mode (Q_o) and impedance at parallel resonance frequency (Rp) of a known DBAR and of a DBAR in accordance with a representative embodiment.

FIGS. **9**A~**9**D are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **10**A~**10**D are cross-sectional views of DBARs in accordance with a representative embodiment.

FIGS. **11**A~**11**B are cross-sectional views of DBARs in accordance with a representative embodiment.

FIG. **12** shows a simplified schematic diagram of an electrical filter in accordance with a representative embodiment.

DEFINED TERMINOLOGY

It is to be understood that the terminology used herein is for purposes of describing particular embodiments only, and is not intended to be limiting. The defined terms are in addition to the technical and scientific meanings of the defined terms as commonly understood and accepted in the technical field of the present teachings.

As used in the specification and appended claims, the terms 'a', 'an' and 'the' include both singular and plural referents, unless the context clearly dictates otherwise. Thus, for example, 'a device' includes one device and plural devices.

As used in the specification and appended claims, and in addition to their ordinary meanings, the terms 'substantial' or 'substantially' mean to within acceptable limits or degree. For example, 'substantially cancelled' means that one skilled in the art would consider the cancellation to be acceptable.

As used in the specification and the appended claims and in addition to its ordinary meaning, the term 'approximately' means to within an acceptable limit or amount to one having ordinary skill in the art. For example, 'approximately the same' means that one of ordinary skill in the art would consider the items being compared to be the same.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation and not limitation, specific details are set forth in order to provide a thorough understanding of illustrative embodiments according to the present teachings. However, it will be apparent to one having ordinary skill in the art having had the benefit of the present disclosure that other embodiments according to the present teachings that depart from the specific details disclosed herein remain within the scope of the appended claims. Moreover, descriptions of well-known apparatuses and methods may be omitted so as to not obscure the description of the illustrative embodiments. Such methods and apparatuses are clearly within the scope of the present teachings.

Generally, it is understood that the drawings and the various elements depicted therein are not drawn to scale. Further, relative terms, such as "above," "below," "top," "bottom," "upper" and "lower" are used to describe the various elements' relationships to one another, as illustrated in the accompanying drawings. It is understood that these relative terms are intended to encompass different orientations of the device and/or elements in addition to the orientation depicted in the drawings. For example, if the device were inverted with respect to the view in the drawings, an element described as "above" another element, for example, would now be below that element.

The present teachings relate generally to BAW resonators, and particularly to DBARs. In certain applications, the BAW resonators provide DBAR-based filters (e.g., ladder filters). Certain details of BAW resonators and filters comprising BAW resonators, materials used therein and methods of fabrication thereof may be found in one or more of the following conunonly owned U.S. Patents and Patent Applications: U.S. Pat. No. 6,107,721, to Lakin; U.S. Pat. Nos. 5,587,620, 5,873,153, 6,060,818, 6,507,983, and 7,629,865 to Ruby, et al.; U.S. Pat. No. 7,280,007, to Feng, et al.; U.S. Patent Publication No. 20070205850 to Jamneala, et al.; U.S. Pat. No. 7,388,454, to Ruby, et al.; U.S. Patent Publication No. 20100327697 to Choy, et al.; and U.S. Patent Publication No. 20100327994 to Choy, et al. The disclosures of these patents and patent applications are specifically incorporated herein by reference. It is emphasized that the components, materials and method of fabrication described in these patents and patent applications are representative and other methods of fabrication and materials within the purview of one of ordinary skill in the art are contemplated.

FIG. **1**A shows a top view of a DBAR **100** in accordance with a representative embodiment. The DBAR **100** comprises a top electrode **101** (referred to below as third electrode **101**), comprising five (5) sides, with a connection side **102** configured to provide the electrical connection to an interconnect **103**. The interconnect **103** provides electrical signals to the top electrode **101** to excite desired acoustic waves in piezoelectric layers (not shown in FIG. **1**) of the DBAR **100**. The top electrode **101** comprises a bridge **104** (referred to below as second bridge **104**) disposed on all sides (the bridge on the connection side **102** cannot be seen in the top view of FIG. **1**A). As described more fully in the parent application, providing the bridge **104** about the perimeter of the DBAR **100** contributes to improved insertion loss and the Q-factor of the odd mode (Q_o) over a desired frequency range (e.g., a passband of the DBAR).

FIG. **1**B shows a cross-sectional view of the DBAR **100** taken along line **1**B-**1**B in accordance with a representative embodiment. The DBAR **100** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**.

A first electrode **107** is disposed over the substrate **105** and partially over the cavity **106**. A planarization layer **107'** is provided over the substrate as shown. In a representative embodiment, the planarization layer **107'** comprises non-etchable borosilicate glass (NEBSG). A first piezoelectric layer **108** is disposed over the first electrode **107**. A second electrode **111** is disposed over the first piezoelectric layer **108**. A planarization layer **109** is also disposed over the first piezoelectric layer **108** and generally does not overlap the cavity **106**. In a representative embodiment, the planarization layer **109** comprises non-etchable borosilicate glass (NEBSG). In an embodiment, the first bridge **110** is disposed along all sides (i.e., along the perimeter) of the DBAR **100**. As should be appreciated by one of ordinary skill in the art, the structure provided by the first electrode **107**, the first piezoelectric layer **108** and a second electrode Ill is a bulk acoustic wave (BAW) resonator, which in this illustrative embodiment comprises a first BAW resonator of the DBAR **100**. A second piezoelectric layer **112** is disposed over the second electrode **111** and over the planarization layer **109**. A third electrode **101** is disposed over the second piezoelectric layer **112**. In an embodiment, the second bridge **104** is disposed along all sides (i.e., along the perimeter) of the DBAR **100**. The structure provided by the second electrode **111**, the second piezoelectric layer **112** and the third electrode **101** is also a BAW resonator, which in this illustrative embodiment comprises a second BAW resonator of the DBAR **100**.

A first bridge **110** is provided at an interface of a second electrode **111** and the planarization layer **109**, and is disposed along all sides of the DBAR **100** (i.e., forms a perimeter of the DBAR **100**). In representative embodiments first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below) have a trapezoidal cross-sectional shape. It is emphasized that the trapezoidal cross-sectional shape of the bridges of the representative embodiments is merely illustrative and the bridges are not limited to a trapezoidal cross-sectional shape. For example, the cross-sectional shape of the bridges of the representative embodiments could be square or rectangular, or of an irregular shape. The "slanting" walls of first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below) is beneficial to the quality of layers (e.g., the quality of the crystalline piezoelectric layer(s)) grown over the first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below). Notably, the first bridge **110** and the second bridge **104** (and other bridges described in connection with representative embodiments below) are not necessarily the same shape (e.g., one could have trapezoidal cross-sectional shape and one could have a rectangular cross-sectional in shape). Typical dimensions of the first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below) are approximately 2.0 μm to approximately 10.0 μm in width (x-dimension in the coordinate system shown in FIG. **1**B) and approximately 150 Å to approximately 3000 Å in height (y-dimension in the coordinate system shown in FIG. **1**B). In certain embodiments, first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below) extend over the cavity **106** (depicted as overlap **113** in FIG. **1**B). The overlap **113** (also referred to as the decoupling region) has a width (x-dimension) of approximately 0.0 μm (i.e., no overlap with the cavity **106**) to approximately 10.0

μm. Notably, the first bridge **110** and the second bridge **104** (and other bridges described in connection with representative embodiments below) do not need to be the same dimensions or located at the same relative position. For example, the overlap **113** of the first and second bridges **110**, **104** with cavity **106** is shown in FIG. 1B to be identical for all bridges **104**, **110**; but this is not essential as different bridges **104**, **110** may overlap the cavity **106** to a greater or lesser extent than other bridges **104**, **110**.

Generally, the first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below) extend over the cavity **106** (depicted as overlap **113** in FIG. 1B). The overlap **113** (also referred to as the decoupling region) has a width (x-dimension) of approximately 0.0 μm (i.e., no overlap with the cavity **106**) to approximately 10.0 μm. Generally, the optimum width of the first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below) depends on the reflection of the eigenmodes at the boundary of an active region **114** (also referred to herein as a DBAR region) and a decoupling region **113** (i.e., the overlap **113**). Due to the lesser thickness of layers in the decoupling region **113**, only complex evanescent modes for the thickness-extensional motion can exist at the operating frequency of the DBAR **100**. These complex evanescent modes are characterized by a characteristic decay length and by a specific propagation constant. The first and second bridges **110**, **104** need to be wide enough to ensure suitable decay of complex evanescent waves excited at the boundary of active region **114** and the decoupling region **113**. Wide bridges minimize tunneling of energy into a field region **115** where propagating modes exist at the frequency of operation.

On the other hand, if the first and second bridges **110**, **104** are too wide, reliability issues can arise and can also limit the placement of similar DBARs (not shown) from being placed in proximity (thus unnecessarily increasing the total area of a chip). In practical situations, the propagating component of the complex evanescent waves can be used to find the optimum width of the first and second bridges **110**, **104**. In general, when the width of the first and second bridges **110** and **104** is equal to an odd multiple of the quarter-wavelength of the complex evanescent wave, the reflectivity of the eigenmodes can be further increased, which can be manifested by parallel resistance Rp and Q-factor attaining maximum values. Typically, depending on the details of the excitation mechanism, other propagating modes of the decoupling region **113**, such as shear modes and flexural modes, can impact Rp and Q-factor. The width of the first and the second bridges **110**, **104** can be modified in view of these other propagating modes. Such optimum width of the first and second bridges **110**, **104** may be determined experimentally.

In addition, the width and position of the first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments) and overlap **113** with the cavity **106** are selected to improve Q-enhancement of the odd resonant mode. In general, the greater the overlap **113** of each bridge **110**, **104** with the cavity **106** of the DBAR **100**, the greater the improvement Q_o with the improvement realized being fairly small after an initial increase. The improvement in Q_o must be weighed against a decrease in the electromechanical effective coupling coefficient kt^2, which decreases with increasing overlap **113** of the first and second bridges **110**, **104** with the cavity **106**. Degradation of kt^2 results in a degradation of insertion loss (S_{21}) of a filter comprising DBARs. As such, the overlap **113** of the first and second bridges **110**, **104** with the cavity **106** is typically optimized experimentally.

The first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below) have a height (y-dimension in the coordinate system of FIG. 1B) of approximately 150 Å to approximately 3000 Å. Notably, the lower limit of the height is determined by the limits of the process of releasing sacrificial material in the forming of the first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments below), and the upper limit of the height is determined by the quality of layers grown over the first and second bridges **110**, **104** (and other bridges described in connection with representative embodiments) and by the quality of subsequent processing of possibly non-planar structures.

Illustratively, the first electrode **107**, second electrode Ill and the third electrode **101** are tungsten (W) having a thickness of approximately 1000 Å to approximately 20000 Å. Other materials may be used for the first electrode **107**, second electrode **111** and the third electrode **101**, including but not limited to molybdenum (Mo), iridium (Ir), copper (Cu), aluminum (Al) or a bi-metal material. Illustratively, the first piezoelectric layer **108** and the second piezoelectric layer **112** are aluminum nitride (AlN) having a thickness of approximately 5000 Å to approximately 25000 Å. Other materials may be used for the first piezoelectric layer **108** and the second piezoelectric layer **112**, including but not limited to ZnO.

The first and second bridges **110**, **104** are formed by patterning a sacrificial material over the first piezoelectric layer **108** and the second piezoelectric layer **112**, and forming the depicted layers thereover. After the layers of the DBAR **100** are formed as desired, the sacrificial material is released leaving the first and second bridges **110**, **104** "filled" with air. In a representative embodiment, the sacrificial material used to form the first and second bridges **110**, **104** is the same as the sacrificial material used to form the cavity **106** (e.g., PSG).

In a representative embodiment, the first bridge **110** and the second bridge **104** define a perimeter along the active region **114** of the DBAR **100**. The active region **114** thus includes the portions of the first BAW resonator and the second BAW resonator disposed over the cavity **106** and bounded by the perimeter provided by the first bridge **110** and the second bridge **104**. As should be appreciated by one of ordinary skill in the art, the active region of the DBAR **100** is bordered around its perimeter by an acoustic impedance discontinuity created at least in part by the first and second bridges **110**, **104**, and above and below (cavity **106**) by an acoustic impedance discontinuity due to the presence of air. Thus, a resonant cavity is beneficially provided in the active region of the DBAR **100**. In certain embodiments, the first bridge **110** and the second bridge **104** are unfilled (i.e., contain air), as is the cavity **106**. In other embodiments described more fully below, the first bridge **110**, or the second bridge **104**, or both, are filled with a material to provide the desired acoustic impedance discontinuity.

It is noted that the first bridge **110**, or the second bridge **104**, or both, do not necessarily have to extend along all edges of the DBAR **100**, and therefore not along the perimeter of the DBAR **100**. For example, the first bridge **110** or the second bridge **104**, or both, may be provided on four "sides" of the five-sided DBAR **100** shown in FIG. **1A**. In certain embodiments, the first bridge **110** is disposed along the same four sides of the DBAR **100** as the second bridge **104**. In other embodiments, the first bridge **110** is disposed along four sides (e.g., all sides but the connection side **102**) of the DBAR **100** and the second bridge **104** is disposed along four sides of the

DBAR **100**, but not the same four sides as the first bridge **110** (e.g., second bridge **104** is disposed along the connection side **102**).

The acoustic impedance mismatch provided by the first bridge **110** and the second bridge **104** causes reflection of acoustic waves at the boundary that may otherwise propagate out of the active region and be lost, resulting in energy loss. The first bridge **110** and the second bridge **104** serve to confine the modes of interest within the active region **114** of the DBAR **100** and reduce energy losses in the DBAR **100**. Reducing such losses serves to increase the Q-factor (Q_o) of the modes of interest in the DBAR **100**. In filter applications of the DBAR **100**, as a result of the reduced energy loss, the insertion loss (S_{21}) is beneficially improved.

Generally, if the frequency of the driving electric field is close to the series resonance frequency for the full wavelength thickness extensional mode (known as the TE2 mode), the TE2 mode is predominantly excited. As mentioned above, the first and second bridges **110**, **104** foster decoupling of the TE2 mode from the laterally propagating modes in the outside field region **115**. However, the edge of the cavity **106** presents a large acoustic impedance discontinuity to the modes that are supported in the decoupling region **113**. That impedance discontinuity couples both evanescent modes (i.e., complex TE2 mode) and propagating modes (e.g., TE1 mode, shear modes and flexural modes) in the decoupling region **113** to the freely propagating modes of the substrate, leading to radiative energy losses and reduction of the Q-factor. Notably, this loss is not addressed by the first and second bridges **110**, **104** which mostly decouple waves propagating in the lateral direction (x-z plane in the coordinate system depicted in FIG. 1B) from the analogous waves propagating along the layers boundaries in the outside field region **115**.

Mitigation of acoustic losses in the vertical direction (y-dimension in the coordinate system depicted in FIG. 1B) of the DBAR **100** is realized by the present teachings through a distributed Bragg reflector (DBR) **118** provided around the perimeter of the cavity **106**. In particular, the DBR **118** comprises first Bragg layers **116-1**, **116-2**, **116-3**, and second Bragg layers **117-1**, **117-2**, but structures with more layers are also possible. The principle of operation of the DBR **118** relies on the fact that due to destructive interference of an incident acoustic wave its total amplitude decays exponentially in the direction of propagation through the stack (in this case away from the interface between first electrode **107** and first Bragg layer **116-1**). In general, such beneficial exponential decay of wave amplitude is only possible if the thicknesses of the layers comprising DBR are equal or close to equal to an odd multiple of the wavelength of an incident acoustic wave. At the bottom of the DBR stack (in this case at the interface between first Bragg layer **116-3** and substrate **105**) the wave amplitude is small, thus yielding negligible radiation of acoustic energy into the substrate **105**. In other words, the acoustic energy incident upon the DBR **118** is being reflected back with only small transmission of acoustic energy into the substrate **105**. Notably, the beneficial reflectivity properties of DBR **118** are in general possible only for a limited range of frequencies, a specific polarization and a limited range of propagation angles of an incident wave. In practical cases when the range of frequencies is given by a bandwidth of the filter and multiple eigenmodes are being excited in the DBAR region the optimal thicknesses of DBR layers are found numerically and experimentally.

The first Bragg layers **116-1**, **116-2**, **116-3** are comparatively low acoustic impedance layers and are provided beneath the first electrode **107** and the planarization layer **107'**; and the second Bragg layers **117-1**, **117-2** having comparatively high acoustic impedance are disposed beneath first Bragg layers **116-1** and **116-2**, respectively. It is noted that the use of five Bragg layers (e.g., first and second Bragg layers **116-1**, **116-2**, **116-3**, **117-1**, **117-2**) is merely illustrative, and the DBR **118** may comprise more than five Bragg layers. The number of Bragg layers provided for the DBR is determined by a tradeoff between expected reflection performance (the more layers the better) and cost and processing issues (the fewer layers the cheaper and more straightforward mirror growth and post-processing).

The amount of acoustic isolation of the excited eigenmodes provided by DBR **118** also depends on the contrast between the acoustic impedances of the adjacent Bragg layers, with a greater amount of contrast creating better acoustic reflection of the vertical component of the eigenmodes. In some embodiments, the first and second Bragg layers **116-1~117-2** are formed of a pair of dielectric materials having contrasting acoustic impedances. One example of such a pair of dielectric materials comprises alternating layers of sputter-deposited silicon carbide (SiC) and plasma enhanced chemical vapor deposited (PECVD) SiC. Notably, the sputter-deposited SiC layer has a comparatively high acoustic impedance and the PECVD SiC layer has a comparatively low acoustic impedance. As such, according to one embodiment, the first Bragg layers **116-1**, **116-2**, **116-3** each comprise PECVD SiC and the second Bragg layers **117-1**, **117-2** each comprise sputter-deposited SiC. Another example of such a pair of dielectric layers is carbon-doped silicon oxide (CDO) and silicon nitride. As such, according to another representative embodiment, the second Bragg layers **117-1**, **117-2** each comprise silicon nitride and the first Bragg layers **116-1**, **116-2**, **116-3** each comprise CDO.

The DBR **118** is formed before the formation of the cavity **106** and the subsequent layers of the DBAR **100**. In particular, the layers of the DBR **118** are provided over the substrate **105** using selected materials deposited by known methods. For example, the first Bragg layer **116-3** may be formed over the substrate **105**, and the second Bragg layer **117-2** is formed over the first Bragg layer **116-3**. In all embodiments, however, the first Bragg layer **116-1**, which has a comparatively low acoustic impedance, is provided beneath the first electrode **107**. The layers of the DBR **118** can be fabricated using various known methods, an example of which is described in U.S. Pat. No. 7,358,831 to Larson, III, et al., the disclosure of which is hereby incorporated by reference.

In general, DBAR **118** is defined by the presence of air (essentially zero impedance material) at both top and bottom boundaries. Therefore vertical stress components are zero at these boundaries. Through the proper selection of materials, the first Bragg layers **116-1**, **116-2**, **116-3** can have a very low acoustic impedance compared to the first electrode **107**, which may also lead to a lowered vertical stress at the boundary between the first electrode **107** and the first Bragg layer **116-1**. Such a lowered stress condition (defining the overall thickness (y-dimension in the depicted coordinate system) of the DBAR) is however only possible when thickness of the first Bragg layer **116-1** is reasonably close to an odd multiple of the quarter wavelength of the fundamental eigenmode (e.g., TE2) for which the DBR **118** is being designed. Adding more layers to the DBR **118** further lowers the vertical stress at the interface between the first electrode **107** and the first Bragg layer **116-1**, thus allowing for closer approximation of an ideal zero-stress condition. However, as mentioned above, while lower vertical stress for the TE2 mode is realized by the selection of the thickness of the first Bragg layer **116-1**, for other modes which are excited either electrically or mechanically (by modal coupling at the lateral edges of the membrane) that must not necessarily be the case and leakage of these modes through the DBR **118** may be actually enhanced (leading to lesser than expected energy confinement).

The first and second Bragg layers **116-1**, **117-1**, **116-2**, **117-2** combined have a thickness (y-dimension of the coordinate system of FIG. **1**B) substantially equal to the depth (y-dimension) of the cavity **106** as depicted in FIG. **1**B. In general, the depth of the cavity **106** is determined by the etch properties of the sacrificial material and by possible downward bowing of the released membrane (i.e., layers of the DBAR **100** disposed over the cavity **106**) in the case of residual compressive stress in the layers of the membrane being present. Usually deeper cavities are more beneficial from the membrane release process point of view, but they also yield somewhat more difficult initial etch process. If the above mentioned features of the release process require deeper cavities than the thickness of the first and second Bragg layers **116-1**, **117-1**, **116-2**, **117-2**, one can increase the depth of the cavity **106** by continued etching the first Bragg layer **116-3**.

The first and second Bragg layers **116-1**, **117-1**, **116-2**, **17-2** have thicknesses in the range of approximately 3000 Å to approximately 50000 Å, depending on the material used and the frequency operating range of the filter. As mentioned above, thickness of all layers comprising the DBR **118** is substantially equal to one quarter-wavelength of the fundamental eigenmode in the selected material and excited at the selected operational frequency (e.g., series resonance frequency). For example, if each of the first Bragg layers **116-1**, **116-2**, **116-3** comprises CDO for operation at 800 MHz (series resonance frequency) the each of the first Bragg layers **116-1**, **116-2**, **116-3** **116** has a thickness of approximately 1.2 μm. In this example, second Bragg layer may comprise SiN, having a thickness of approximately 3.2 μm for operation at 800 MHz. Notably, the thickness of all layers of the DBR **118** can be selected to be odd-multiple (e.g., 3) quarter-wavelengths of the fundamental DBAR eigenmode in the selected material (e.g., if one quarter-wavelength layer is too thin for practical processing).

After the first and second Bragg layers **116-1**, **117-1**, **116-2** deposited, the cavity **106** is etched according to a known method and filled with a sacrificial layer, such as described in U.S. Pat. No. 6,060,818. The remaining layers of the DBAR **100** are then provided over the filled cavity and the first and second Bragg layers **116-1**, **117-1**, **116-2** using a known method such as described above, in the parent application and/or one or more of the incorporated patents and patent publications referenced above.

In the representative embodiment shown and described in connection with FIGS. 1A, 1B, the first and second bridges **110**, **104** were unfilled (i.e., contained air as the acoustic medium). FIG. **1**C shows a cross-sectional view of DBAR **100** including the DBR **118** in accordance with another representative embodiment. In the DBAR **100** depicted in FIG. **1**C in both bridges are filled with a material to provide the acoustic impedance discontinuity to reduce losses. In certain embodiments, first bridge **110'** and second bridge **104'** are filled with NEBSG, CDO, silicon carbide (SiC) or other suitable dielectric material that will not release when the sacrificial material disposed in the cavity **106** is released. In other embodiments, first bridge **110'** and second bridge **104'** are filled with one of tungsten (W), molybdenum (Mo), copper (Cu), iridium (Ir) or other suitable metal materials (e.g., alloys) that will not release when the sacrificial material disposed in the cavity **106** is released. The first and second bridges **110'**, **104'** are fabricated by forming the NEBSG or other fill material over the first piezoelectric layer **108** and over the second piezoelectric layer **112** by a known method, and forming respective layers of the DBAR **100** thereover. When the cavity **106** is formed through the release of the sacrificial, the first bridge **110'** and the second bridge **104'** remain “filled” with the selected material.

FIG. **1**D shows a cross-sectional view of DBAR **100** including the DBR **118** in accordance with another representative embodiment. In the DBAR **100** depicted in FIG. **1**D the second bridge **104'** is filled with a material to provide the acoustic impedance discontinuity to reduce losses, and the first bridge **110** is filled with air. This modification of the DBAR **100** is fabricated by patterning a material (e.g., NEBSG) over the second piezoelectric layer **112** that will not release before forming the third electrode **101**. The first bridge **110** is formed by patterning a sacrificial material over the first electrode **107**, and releasing the sacrificial material as described above.

FIG. **1**E shows a cross-sectional view of DBAR **100** including the DBR **118** in accordance with another representative embodiment. In the DBAR **100** depicted in FIG. **1**E the second bridge **104** is filled with air, and the first bridge **110'** is filled with a material to provide the acoustic impedance discontinuity to reduce losses. This modification of the DBAR **100** is fabricated by patterning a material (e.g., NEBSG) over the first piezoelectric layer **108** that will not release before forming the second electrode **111**. The second bridge **104** is formed by patterning a sacrificial material over the first piezoelectric layer **108**, and releasing the sacrificial material as described above.

Embodiments Comprising a Single Bridge

In the embodiments described presently, a single bridge is provided in an illustrative DBAR. The single bridge is provided at a single layer in each embodiment, and forms a perimeter that encloses the active region of the DBAR. By placing the bridge under different layers, the various embodiments can be studied to test the degree of coupling of modes in the active region (DBAR region) and the modes in the field region. Generally, the bridge decouples modes with a comparatively large propagation constant (k_r) from the modes in the field region. As described below, certain embodiments comprise a “filled” bridge and certain embodiments comprise an “unfilled” bridge. Many details of the present embodiments are common to those described above in connection with the representative embodiments of FIGS. **1**A-**1**F. Generally, the common details are not repeated in the description of embodiments comprising a single bridge.

FIGS. **2**A~B show cross-sectional views of a DBAR **200** in accordance with a representative embodiment. The DBAR **200** depicted in FIGS. **2**A~**2**B comprises the DBR **118** described in detail above. The DBR **118** comprises materials and is fabricated in accordance with representative embodiments described above. Generally, the details of the DBR **118** are not repeated to prevent obscuring the description of the representative embodiments. A bridge **201** provided in the first piezoelectric layer **108**. The bridge **201** is unfilled (i.e., filled with air). Bridge **201** is disposed around the perimeter of the active region **114** of the DBAR **200**, and fosters confinement of modes in the active region **114** of the DBAR **200**. For purposes of illustration of the improvement in mode confinement in the active region **114** of the DBAR **200**, bridge **201** having a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** of the cavity **106** by 5.0 μm was provided. An increase in Q_o of approximately 200% (depending on frequency of operation, e.g. at 0.87 GHz) is expected compared to a known DBAR that does not include a bridge

FIG. **2**B shows a bridge **202** provided in the first piezoelectric layer **108** of DBAR **200**. The bridge **202** is "filled" with a material (e.g., NEBSG or other material described above) to provide an acoustic impedance discontinuity. Bridge **202** is disposed around the perimeter of the active region **114** of the DBAR **200**, and fosters confinement of modes in the active region **114** of the DBAR **200**. Similar improvements in Q_o expected for bridge **201** are expected with the use of bridge **202**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIGS. **3**A~**3**B show a cross-sectional view of a DBAR **300** in accordance with a representative embodiment. The DBAR **300** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **300** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **300** are common to those of DBARs **100**, **200**, described above, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **3**A shows a bridge **301** provided in the second electrode Ill and into the planarization layer **109**. The bridge **301** is unfilled (i.e., filled with air). Bridge **301** is disposed along the perimeter of the active region **114** of the DBAR **300**, and fosters confinement of modes in the active region **114** of the DBAR **300**. For purposes of illustration of the improvement in mode confinement in the active region **114** of the DBAR **200**, bridge **201** having a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** of the cavity **106** by 5.0 μm was provided. An increase in Q_o of approximately 200% (depending on frequency of operation, e.g. at 0.87 GHz) is expected compared to a known DBAR that does not include a bridge.

FIG. **3**B shows a bridge **302** provided in the second electrode **111**. The bridge **302** is "filled" with a material (e.g., NEBSG or other material described above) to provide an acoustic impedance discontinuity. Bridge **302** is disposed along the perimeter of the active region **114** of the DBAR **300**, and fosters confinement of modes in the active region **114** of the DBAR **300**. For bridge **302** having the same width, height and overlap **113** of cavity **106** as bridge **301**, similar improvements in Q_o expected for bridge **301** are expected with the use of bridge **302**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIGS. **4**A~**4**B show cross-sectional views of a DBAR **400** in accordance with a representative embodiment. The DBAR **400** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **400** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **400** are common to those of DBARs **100~300**, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **4**A shows a bridge **401** provided in the second piezoelectric layer **112**. The bridge **401** is unfilled (i.e., filled with air). Bridge **401** is disposed around the perimeter of the active region **114** of the DBAR **400**, and fosters confinement of modes in the active region of the DBAR **400**. For purposes of illustration of the improvement in mode confinement in the active region **114** of the DBAR **400**, bridge **401** having a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** of the cavity **106** by 5.0 μm was provided. An increase in Q_o of approximately 200% (depending on frequency of operation, e.g. at 0.87 GHz) is expected compared to a known DBAR that does not include a bridge.

FIG. **4**B shows a bridge **402** provided in the second piezoelectric layer **112**. The bridge **402** is "filled" with a material (e.g., NEBSG or other material described above) to provide an acoustic impedance discontinuity. Bridge **402** is disposed around the perimeter of the active region **114** of the DBAR **400**, and fosters confinement of modes in the active region **114** of the DBAR **400**. For bridge **402** having the same width, height and overlap **113** of cavity **106** as bridge **401**, similar improvements in Q_o expected for bridge **401** are expected with the use of bridge **402**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIGS. **5**A~**5**B show a cross-sectional view of a DBAR **500** in accordance with a representative embodiment. The DBAR **500** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **500** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **500** are common to those of DBARs **100-400**, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **5**A shows a bridge **501** provided in the third electrode **101**. The bridge **501** is unfilled (i.e., filled with air). Bridge **501** is disposed around the perimeter of the active region **114** of the DBAR **500**, and fosters confinement of modes in the active region **114** of the DBAR **500**. For purposes of illustration of the improvement in mode confinement in the active region **114** of the DBAR **500**, bridge **501** having a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** of the cavity **106** by 2.0 μm was provided. An increase in Q_o of approximately 200% (depending on frequency of operation, e.g. at 0.87 GHz) is expected compared to a known DBAR that does not include a bridge.

FIG. **5**B shows a bridge **502** provided in the third electrode **101**. The bridge **502** is "filled" with a material (e.g., NEBSG or other material described above) to provide an acoustic impedance discontinuity. Bridge **502** is disposed along the perimeter of the active region **114** of the DBAR **500**, and fosters confinement of modes in the active region **114** of the DBAR **500**. For bridge **502** having the same width, height and overlap **113** of cavity **106** as bridge **501**, similar improvements in Q_o expected for bridge **501** are expected with the use of bridge **502**. Beneficially, the use of a filled bridge provides a more rugged structure.

Embodiments Comprising Two Bridges

In the embodiments described presently, two bridges are provided in an illustrative DBAR. One bridge is provided in one layer of the DBAR and a second bridge is provided in another layer of the DBAR in each embodiment. The bridges are generally concentric, although not circular in shape, and are disposed about a perimeter that encloses the active region of the DBAR. By placing the bridges under different combinations of layers, the various embodiments can be studied to test the degree of coupling of modes in the active region **114** (DBAR region) and the modes in the field region **115**. Generally, the bridge decouples modes with a comparatively large propagation constant (k_r) from the modes in the field region **115**. As described below, certain embodiments comprise a "filled" bridge and certain embodiments comprise an "unfilled" bridge.

FIGS. **6**A~**6**D show a cross-sectional view of a DBAR **600** in accordance with a representative embodiment. The DBAR **600** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **600** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **600** are common to those of DBARs **100~500**, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **6**A shows a first bridge **601** provided in the first piezoelectric layer **108**. The first bridge **601** is unfilled (i.e., filled with air). A second bridge **602** is provided in the third electrode **101**. The second bridge **602** is unfilled (i.e., filled with air). First and second bridges **601**, **602** are disposed along the perimeter of the active region **114** of the DBAR **600**, and foster confinement of modes in the active region of the DBAR **600**. For purposes of illustration of the improvement in mode confinement in the active region of the DBAR **600**, first and second bridges **601**, **602** each having a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** the cavity **106** by 5.0 μm are provided. Compared to a known DBAR without bridges (depending on frequency of operation, e.g. at 0.87 GHz), an improvement of approximately 400% in Q_o for the DBAR **600** is expected due to the increased confinement of an odd mode in the DBAR **600** by use of first and second bridges **601**, **602** of the representative embodiment.

FIG. **6**B shows a first bridge **603** provided in the first piezoelectric layer **108**. The first bridge **603** is filled (e.g., filled with NEBSG). A second bridge **604** is provided in the third electrode **101**. The second bridge **804** is also filled. First and second bridges **603**, **604** are disposed around the perimeter of the active region of the DBAR **600**, and foster confinement of modes in the active region of the DBAR **600**. For first and second bridges **603**, **604** having the same width, height and overlap **113** of cavity **106** as first and second bridges **601**, **602** similar improvements in Q_o expected for first and second bridges **601**, **602** are expected with the use of first and second bridges **603**, **604**. Beneficially, the use of filled bridges provides a more rugged structure.

FIG. **6**C shows a first bridge **601** provided in the first piezoelectric layer **108**. The first bridge **601** is unfilled (i.e., filled with air). Second bridge **604** is provided in the third electrode **101**. The second bridge **604** is filled. First and second bridges **601**, **604** are disposed around the perimeter of the active region **114** of the DBAR **600**, and foster confinement of modes in the active region **114** of the DBAR **600**. For first and second bridges **601**, **604** having the same width, height and overlap **113** of cavity **106** as first and second bridges **601**, **602** similar improvements in Q_o expected for first and second bridges **601**, **602** are expected with the use of first and second bridges **601**, **604**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **6**D shows first bridge **603** provided in the first piezoelectric layer **108**. The first bridge **603** is filled. A second bridge **602** is provided in the third electrode **101**. The second bridge **602** is unfilled (i.e., filled with air). First and second bridges **603**, **602** are disposed along the perimeter of the active region **114** of the DBAR **600**, and foster confinement of modes in the active region **114** of the DBAR **600**. For first and second bridges **603**, **602** having the same width, height and overlap **113** of cavity **106** as first and second bridges **601**, **602**, similar improvements in Q_o expected for first and second bridges **601**, **602** are expected with the use of first and second bridges **603**, **602**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIGS. **7**A-**7**D show cross-sectional views of a DBAR **700** in accordance with a representative embodiment. The DBAR **700** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **300** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **700** are common to those of DBARs **100**-**600**, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **7**A shows a first bridge **701** provided in the first piezoelectric layer **108**. The first bridge **701** is unfilled (i.e., filled with air). A second bridge **702** is provided in the second electrode Ill and extends partially into the planarization layer **109**. The second bridge **702** is unfilled (i.e., filled with air). First and second bridges **701**, **702** are disposed along the perimeter of the active region **114** of the DBAR **700**, and foster confinement of modes in the active region **114** of the DABR. For purposes of illustration of the improvement in mode confinement in the active region of the DBAR **700**, first and second bridges **701**, **702** each have a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** the cavity **106** by 5.0 μm. Compared to a known DBAR without bridges (depending on frequency of operation, e.g. at 0.87 GHz), an improvement of approximately 400% in Q_o for the DBAR **700** is expected due to the increased confinement of an odd mode in the DBAR **700** by use of first and second bridges **701**, **702** of the representative embodiment.

FIG. **7**B shows a first bridge **703** provided in the first piezoelectric layer **108**. The first bridge **703** is filled. A second bridge **704** is provided in the second electrode **111** and extends partially into the planarization layer **109**. The second bridge **704** is filled. First and second bridges **703**, **704** are disposed along the perimeter of the active region **114** of the DBAR **700**, and foster confinement of modes in the active region **114** of the DBAR **700**. For first and second bridges **703**, **704** having the same width, height and overlap of cavity **106** as first and second bridges **701**, **702**, similar improvements in Q_o expected for first and second bridges **701**, **702** are expected with the use of first and second bridges **703**, **704**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **7**C shows first bridge **701** provided in the first piezoelectric layer **108**. The first bridge **701** is unfilled (i.e., filled with air). Second bridge **704** is provided in the second electrode **111** and extends partially into the planarization layer **109**. The second bridge **704** is filled. First and second bridges **701**, **704** are disposed along the perimeter of the active region of the DBAR **700**, and foster confinement of modes in the active region of the DBAR **700**. For first and second bridges **701**, **704** having the same width, height and overlap of cavity **106** as first and second bridges **701**, **702**, similar improvements in Q_o expected for first and second bridges **701**, **702** are expected with the use of first and second bridges **701**, **704**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **7**D shows first bridge **703** provided in the first piezoelectric layer **108**. The first bridge **703** is filled. Second bridge **702** is provided in the second electrode **111** and extends partially into the planarization layer **109**. The second bridge **702** is unfilled (i.e., filled with air). First and second bridges **703**, **702** are disposed around the perimeter of the active region of the DBAR **700**, and foster confinement of modes in the active region **114** of the DBAR **700**. For first and second bridges **703**, **702** having the same width, height and overlap of cavity **106** as first and second bridges **701**, **702**, similar improvements in Q_o expected for first and second bridges **701**, **702** are expected with the use of first and second bridges **703**, **702**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIGS. **8**A-**8**D show cross-sectional views of a DBAR **800** in accordance with a representative embodiment. The DBAR **800** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **800** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **800** are common to those of DBARs **100**-**700**, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **8**A shows a first bridge **801** provided in the first piezoelectric layer **108**. The first bridge **801** is unfilled (i.e., filled with air). A second bridge **802** is provided in the second piezoelectric layer **112**. The second bridge **802** is unfilled (i.e., filled with air). First and second bridges **801**, **802** are disposed along the perimeter of the active region **114** of the

DBAR **800**, and foster confinement of modes in the active region **114** of the DBAR **800**. For purposes of illustration of the improvement in mode confinement in the active region of the DBAR **800**, first and second bridges **801**, **802** each having a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** of the cavity **106** by 5.0 μm are provided. Compared to a known DBAR without bridges (depending on frequency of operation, e.g. at 0.87 GHz), an improvement of approximately 400% in Q_o for the DBAR **800** is expected due to the increased confinement of an odd mode in the DBAR **800** by use of first and second bridges **801**, **802** of the representative embodiment.

FIG. **8**B shows a first bridge **803** provided in the first piezoelectric layer **108**. The first bridge **803** is filled. Second bridge **804** is provided in the second piezoelectric layer **112**. The second bridge **804** is filled. First and second bridges **803**, **804** are disposed along the perimeter of the active region **114** of the DBAR **800**, and foster confinement of modes in the active region of the DBAR **800**. For first and second bridges **803**, **804** having the same width, height and overlap **113** of cavity **106** as first and second bridges **801**, **802**, similar improvements in Q_o expected for first and second bridges **801**, **802** are expected with the use of first and second bridges **803**, **804**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **8**C shows first bridge **801** provided in the first piezoelectric layer **108**. The first bridge **801** is unfilled. Second bridge **804** is provided in the second piezoelectric layer **112**. The second bridge **804** is unfilled. First and second bridges **801**, **804** are disposed along the perimeter of the active region **114** of the DBAR **800**, and foster confinement of modes in the active region **114** of the DBAR **800**. For first and second bridges **801**, **804** having the same width, height and overlap **113** of cavity **106** as first and second bridges **801**, **802**, similar improvements in Q_o expected for first and second bridges **801**, **802** are expected with the use of first and second bridges **801**, **804**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **8**D shows first bridge **803** provided in the first piezoelectric layer **108**. The first bridge **803** is filled. Second bridge **802** is provided in the second piezoelectric layer **112**. The second bridge **802** is unfilled. First and second bridges **803**, **802** are disposed along the perimeter of the active region **114** of the DBAR **800**, and foster confinement of modes in the active region **114** of the DBAR **800**. For first and second bridges **803**, **802** having the same width, height and overlap **113** of cavity **106** as first and second bridges **801**, **802**, similar improvements in Q_o expected for first and second bridges **801**, **802** are expected with the use of first and second bridges **803**, **802**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **8**E shows a comparison of simulated the odd mode Q (Q_o) versus frequency of DBAR **800** of the representative embodiment depicted in FIG. **8**A and odd mode Q (Q_o) of a known DBAR. The Q factor affects roll-off of a filter comprising the DBAR **800**, and varies according to various material properties of the DBAR **800**, such as a series resistance Rs and a parallel resistance Rp, which correspond to various heat losses and acoustic losses of the DBAR **800**. Generally, it is beneficial to maximize Q and Rp, and to minimize Rs for the most optimal insertion and rejection loss characteristics of the filter comprising DBARs **800**.

As shown in FIG. **8**A, the first and second bridges **110**, **104** are released. For purposes of illustration of the improvement in mode confinement in the active region **114** of the DBAR **800**, first and second bridges, **110**, **104** having a width (x-dimension) of approximately 5.5 μm, a height of 2000 Å, and overlap **113** of 5.0 μm are provided. The DBR **118** comprises the first Bragg layers **116-1**, **116-2**, **116-3** made of PECVD-SiC having thickness approximately 1.8 μm and the second Bragg layers **117-1**, **116-2** made of sputtered-SiC having thickness approximately 3 μm.

Curve **805** depicts Q_o of a mode in a known DBAR (without bridges or DBR in accordance with representative embodiments) and curve **806** depicts Q_o of a mode in DBAR **800** with first and second bridges (**110**, **104**) released. Compared to the known DBAR that does not include a bridge or DBR **118**, an increase in Q_o of approximately 400% (depending on frequency of operation, e.g. at 0.87 GHz) is numerically predicted.

Curve **807** depicts Rp at parallel resonance Fp of a known DBAR (without bridges or DBR in accordance with representative embodiments) and curve **808** depicts Rp at parallel resonance Fp of a mode in DBAR **800** with first and second bridges (**110**, **104**) released. As can be appreciated, Rp of DBAR **800** peaks at approximately 4200, and Rp of the known DBAR peaks at approximately 1400. As such, an improvement of approximately 300% is realized through the implementations various features of the DBAR **800** of the present teachings.

FIGS. **9**A~**9**D show cross-sectional views of a DBAR **900** in accordance with a representative embodiment. The DBAR **900** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **900** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **900** are common to those of DBARs **100-800**, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **9**A shows a first bridge **901** provided in the second electrode **111** and extending partially into the planarization layer **109**. The first bridge **901** is unfilled (i.e., filled with air). A second bridge **902** is provided in the second piezoelectric layer **112**. The second bridge **902** is unfilled (i.e., filled with air). First and second bridges **901**, **902** are disposed along the perimeter of the active region **114** of the DBAR **900**, and foster confinement of modes in the active region **114** of the DBAR **900**. For purposes of illustration of the improvement in mode confinement in the active region of the DBAR **900**, first and second bridges **901**, **902** each having a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** of the cavity **106** by 5.0 μm are provided. Compared to a known DBAR without bridges (depending on frequency of operation, e.g. at 0.87 GHz), an improvement of approximately 400% in Q_o for the DBAR **900** is expected due to the increased confinement of an odd mode in the DBAR **900** by use of first and second bridges **901**, **902** of the representative embodiment.

FIG. **9**B shows a first bridge **903** provided in the second electrode **111** and extending partially into the planarization layer **109**. The first bridge **903** is filled. A second bridge **904** is provided in the second piezoelectric layer **112**. The second bridge **904** is filled. First and second bridges **903**, **904** are disposed along the perimeter of the active region **114** of the DBAR **900**, and foster confinement of modes in the active region **114** of the DBAR **900**. For first and second bridges **903**, **904** having the same width, height and overlap **113** of cavity **106** as first and second bridges **901**, **902** similar improvements in Q_o expected for first and second bridges **901**, **902** are expected with the use of first and second bridges **903**, **904**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **9**C shows a first bridge **901** provided in the second electrode **111** and extending partially into the planarization layer **109**. The first bridge **901** is unfilled (i.e., filled with air).

Second bridge **904** is provided in the second piezoelectric layer **112**. The second bridge **904** is filled. First and second bridges **901**, **904** are disposed along the perimeter of the active region **114** of the DBAR **900**, and foster confinement of modes in the active region **114** of the DBAR **900**. For first and second bridges **901**, **904** having the same width, height and overlap **113** of cavity **106** as first and second bridges **901**, **902** similar improvements in Q_o expected for first and second bridges **901**, **902** are expected with the use of first and second bridges **901**, **904**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **9**D shows first bridge **903** provided in the second electrode **111** and extending partially into the planarization layer **109**. The first bridge **903** is filled. Second bridge **902** is provided in the second piezoelectric layer **112**. The second bridge **902** is unfilled (i.e., filled with air). First and second bridges **903**, **902** are disposed along the perimeter of the active region **114** of the DBAR **900**, and foster confinement of modes in the active region **114** of the DBAR **900**. For first and second bridges **903**, **902** having the same width, height and overlap **113** of cavity **106** as first and second bridges **901**, **902** similar improvements in Q_o expected for first and second bridges **901**, **902** are expected with the use of first and second bridges **903**, **902**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIGS. **10**A~**10**D show cross-sectional views of a DBAR **1000** in accordance with a representative embodiment. The DBAR **1000** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **100** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **1000** are common to those of DBARs **100-900**, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **10**A shows a first bridge **1001** provided in the second piezoelectric layer **112**. The first bridge **1001** is unfilled (i.e., filled with air). A second bridge **1002** is provided in the third electrode **101**. The second bridge **1002** is unfilled (i.e., filled with air). First and second bridges **1001**, **1002** are disposed around the perimeter of the active region **114** of the DBAR **1000**, and foster confinement of modes in the active region **114** of the DBAR **1000**. For purposes of illustration of the improvement in mode confinement in the active region of the DBAR **1000**, first and second bridges **1001**, **1002** each having a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** of the cavity **106** by 5.0 μm are provided. Compared to a known DBARs without bridges (depending on frequency of operation, e.g. at 0.87 GHz), an improvement of approximately 400% in Q_o for the DBAR **1000** is expected due to the increased confinement of an odd mode in the DBAR **1000** by use of first and second bridges **1001**, **1002** of the representative embodiment.

FIG. **10**B shows a first bridge **1003** provided in the second piezoelectric layer **112**. The first bridge **1003** is filled. A second bridge **1004** is provided in the third electrode **101**. The second bridge **1004** is filled. First and second bridges **1003**, **1004** are disposed around the perimeter of the active region **114** of the DBAR **1000**, and foster confinement of modes in the active region **114** of the DBAR **1000**. For first and second bridges **1003**, **1004** having the same width, height and overlap **113** of cavity **106** as first and second bridges **1001**, **1002** similar improvements in Q_o expected for first and second bridges **1001**, **1002** are expected with the use of first and second bridges **1003**, **1004**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **10**C shows first bridge **1001** provided in the second piezoelectric layer **112**. The first bridge **1001** is unfilled (i.e., filled with air). Second bridge **1004** is provided in the third electrode **101**. The second bridge **1004** is filled. First and second bridges **1001**, **1004** are disposed around the perimeter of the active region **114** of the DBAR **1000**, and foster confinement of modes in the active region **114** of the DBAR **1000**. For first and second bridges **1001**, **1004** having the same width, height and overlap **113** of cavity **106** as first and second bridges **1001**, **1002** similar improvements in Q_o expected for first and second bridges **1001**, **1002** are expected with the use of first and second bridges **1001**, **1004**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **10**D shows first bridge **1003** provided in the second piezoelectric layer **112**. The first bridge **1003** is filled. Second bridge **1002** is provided in the third electrode **101**. The second bridge **1002** unfilled (i.e., filled with air). First and second bridges **1003**, **1002** are disposed around the perimeter of the active region **114** of the DBAR **1000**, and foster confinement of modes in the active region **114** of the DBAR **1000**. For first and second bridges **1003**, **1002** having the same width, height and overlap **113** of cavity **106** as first and second bridges **1001**, **1002** similar improvements in Q_o expected for first and second bridges **1001**, **1002** are expected with the use of first and second bridges **1003**, **1002**. Beneficially, the use of a filled bridge provides a more rugged structure.

FIG. **11**A shows a cross-sectional view of a DBAR **1100** in accordance with a representative embodiment. The DBAR **1100** comprises a plurality of layers disposed over a substrate **105** having a cavity **106**. The DBAR **1100** also comprises the DBR **118** described in detail above. Many aspects of the DBAR **1100** are common to those of DBARs **100-1000**, and are not repeated in order to avoid obscuring the description of the representative embodiments presently described.

FIG. **11**A shows first bridge **110** provided in the second electrode **111** and extending into the planarization layer **109**. The first bridge **110** is unfilled (i.e., filled with air). Second bridge **104** is provided in the third electrode **101**. The second bridge **102** is unfilled (i.e., filled with air). First and second bridges **110**, **104** are disposed along the perimeter of the active region **114** of the DBAR **1100**, and foster confinement of modes in the active region of the DBAR **1100**. Illustratively, first and second bridges **110**, **104** each have a width (x-dimension) of approximately 5.5 μm, a height of 500 Å, and overlap **113** the cavity **106** by 5.0 μm.

An inner raised region **1101** is provided over the third electrode **101** in the active region **114**. The inner raised region **1101** is separated from the edges of the active region by gaps **1102**, each having a width (in the x-dimension of the coordinate system shown in FIG. **11**A) of approximately 1.0 μm to approximately 10.0 μm and a thickness (in the y-dimension of the coordinate system shown in FIG. **11**A) of approximately 100 Å to approximately 1000 Å, depending on the product performance needs. Many details of the inner raised region **1101** are described in commonly owned U.S. patent application Ser. No. 13/074,094, entitled "Stacked Bulk Acoustic Resonator and Method of Fabricating Same" filed on Mar. 29, 2011, to Alexandre Shirakawa, et al. The disclosure of this U.S. Patent Application is specifically incorporated herein by reference.

FIG. **11**B shows first bridge **110** provided in the second electrode **111** and extending into the planarization layer **109**. The first bridge **110** is unfilled (i.e., filled with air). Second bridge **104** is provided in the third electrode **101**. The second bridge **102** is unfilled (i.e., filled with air). The DBAR **1100** depicted in FIG. **11**B includes inner raised region **1101** and an outer raised region **1103** disposed over the third electrode **101**. The outer raised region **1103** abuts the edge of the active region **114** as depicted in FIG. **11**B, and has a width (in the x-dimension of the coordinate system shown in FIG. **11**B) of approximately 1.0 μm to approximately 10.0 μm and a thickness (in the y-dimension of the coordinate system shown in FIG. **11**B) of approximately 500 Å to approximately 5000 Å, depending on the product performance needs. Many details of the outer raised region **1103** are provided in U.S. patent application Ser. No. 13/074,094, entitled "Stacked Bulk Acoustic Resonator and Method of Fabricating Same" filed on Mar. 29, 2011, to Alexandre Shirakawa, et al. and incorporated herein by reference above.

When connected in a selected topology, a plurality of DBRs according to representative embodiments described above can function as an electrical filter. FIG. **12** depicts a simplified schematic block diagram of an electrical filter **1200** in accordance with a representative embodiment. The electrical filter **1200** comprises series acoustic resonators **1201** and shunt acoustic resonators **1202**. Notably, individual DBARs of the representative embodiments described above can be selectively connected to one another, to ground and to input terminals and output terminals to form electrical filter **1200**. The electrical filter **1200** is commonly referred to as a ladder filter, and may be used for example in duplexer applications. Further details of a ladder-filter arrangement may be as described for example in U.S. Pat. No. 5,910,756 to Ella, and U.S. Pat. No. 6,262,637 to Bradley, et al. The disclosures of these patents are specifically incorporated by reference. It is emphasized that the topology of the electrical filter **1200** is merely illustrative and other topologies are contemplated. Moreover, the acoustic resonators of the representative embodiments are contemplated in a variety of applications besides duplexers.

In accordance with illustrative embodiments, BAW resonators comprising bridges and their methods of fabrication are described. One of ordinary skill in the art appreciates that many variations that are in accordance with the present teachings are possible and remain within the scope of the appended claims. These and other variations would become clear to one of ordinary skill in the art after inspection of the specification, drawings and claims herein. The invention therefore is not to be restricted except within the spirit and scope of the appended claims.

The invention claimed is:

1. A bulk acoustic wave (BAW) resonator, comprising:
- a first layer comprising a plurality of sub-layers, wherein a cavity exists in the first layer, the cavity having a perimeter bordering an active region of the BAW resonator;
- a distributed Bragg reflector (DBR) bordering the cavity and comprising: the plurality of sub-layers, wherein each of the sub-layers has a thickness substantially equal to an odd multiple of the quarter wavelength of the fundamental eigenmode of the BAW resonator; and a second layer disposed beneath the first layer and the cavity;
- a first electrode disposed over the cavity;
- a first piezoelectric layer disposed over the first electrode;
- a second electrode disposed over the first piezoelectric layer;
- a second piezoelectric layer disposed over the second electrode;
- a third electrode disposed over the second piezoelectric layer; and
- a bridge disposed between the first electrode and the third electrode.

2. A BAW resonator as claimed in claim **1**, further comprising a planarization layer disposed adjacent to the second electrode.

3. A BAW resonator as claimed in claim **2**, wherein the bridge is disposed partly in the planarization layer and partly in the second electrode.

4. A BAW resonator as claimed in claim **1**, wherein the plurality of sub-layers comprise layers having alternating low acoustic impedance and high acoustic impedance relative to one another.

5. A BAW resonator as claimed in claim **4**, wherein each of the low acoustic impedance sub-layers comprise first layers of silicon carbide and each of the high acoustic impedance sub-layers comprise second layers of silicon carbide.

6. A BAW resonator as claimed in claim **1**, wherein the second layer is a substrate of the BAW resonator.

7. A BAW resonator as claimed in claim **1**, further comprising a substrate disposed beneath the second layer of the DBR.

8. A BAW resonator as claimed in claim **1**, wherein the bridge is disposed over the distributed Bragg reflector and at least partially overlaps the distributed Bragg reflector.

9. A BAW resonator as claimed in claim **1**, wherein the bridge at least partially overlaps the cavity.

10. A RAW resonator as claimed in claim **1**, wherein the bridge is a first bridge, and the BAW resonator further comprises a second bridge disposed between the first electrode and the third electrode.

11. A BAW resonator as claimed in claim **10**, wherein the BAW resonator has a second perimeter bordering the active region of the BAW resonator, and the second bridge is disposed along the second perimeter.

12. A BAW resonator as claimed in claim **10**, wherein the first bridge and the second bridge each comprise a fill material having acoustic impedance.

13. A BAW resonator as claimed in claim **12**, wherein the fill material comprises one or more of a dielectric material, a metal, or an alloy of metals.

14. A BAW resonator as claimed in claim **10**, wherein the first bridge comprises a fill material having an acoustic impedance and the second bridge comprises air.

15. A BAW resonator as claimed in claim **10**, wherein the first bridge is disposed in the first piezoelectric layer and the second bridge is disposed in the second piezoelectric layer.

16. A BAW resonator as claimed in claim **1**, wherein the bridge comprises a fill material having an acoustic impedance.

17. A BAW resonator as claimed in claim **16**, wherein the fill material comprises one or more of a dielectric material, a metal, or an alloy of metals.

18. A BAW resonator as claimed in claim **1**, wherein the bridge has a trapezoidal cross-sectional shape.

19. An electrical filter comprising the BAW resonator as claimed in claim **1**.

20. A bulk acoustic wave (BAW) resonator, comprising:
- a first layer comprising a plurality of sub-layers, wherein a cavity exists in the first layer, the cavity having a perimeter bordering an active region of the BAW resonator;
- a distributed Bragg reflector (DBR) bordering the cavity and comprising: the plurality of sub-layers, wherein each of the sub-layers has a thickness substantially equal to an odd multiple of the quarter wavelength of the fundamental eigenmode of the BAW resonator; and a second layer disposed beneath the first layer and the cavity;
- a first electrode disposed over the cavity;
- a first piezoelectric layer disposed over the first electrode;
- a second electrode disposed over the first piezoelectric layer;

a second piezoelectric layer disposed over the second electrode;

a third electrode disposed over the second piezoelectric layer;

a bridge disposed between the first electrode and the third electrode; and

an inner raised region disposed over the third electrode, or an outer raised region disposed over the third electrode, or both the inner raised region and the outer raised region.

21. A BAW resonator as claimed in claim **20**, further comprising a planarization layer disposed adjacent to the second electrode.

22. A BAW resonator as claimed in claim **21**, wherein the bridge is disposed partly in the planarization layer and partly in the second electrode.

23. A BAW resonator as claimed in claim **20**, wherein the plurality of sub-layers comprise sub-layers having alternating low acoustic impedance and high acoustic impedance relative to one another.

24. A BAW resonator as claimed in claim **23**, wherein each of the sub-layers having low acoustic impedance comprise first layers of silicon carbide and each of the sub-layers having high acoustic impedance comprise second layers of silicon carbide.

25. A BAW resonator as claimed in claim **20**, wherein the second layer is a substrate of the BAW resonator.

26. A BAW resonator as claimed in claim **20**, further comprising a substrate disposed beneath the second layer of the DBR.

27. A BAW resonator as claimed in claim **20**, wherein the bridge is disposed over the distributed Bragg reflector and at least partially overlaps the distributed Bragg reflector.

28. A BAW resonator as claimed in claim **20**, wherein the bridge at least partially overlaps the cavity.

29. A BAW resonator as claimed in claim **20**, wherein the bridge is a first bridge, and the BAW resonator further comprises a second bridge disposed between the first electrode and the third electrode.

30. A BAW resonator as claimed in claim **29**, wherein the BAW resonator has a second perimeter bordering the active region of the BAW resonator, and the second bridge is disposed along the second perimeter.

31. A BAW resonator as claimed in claim **29**, wherein the first bridge is disposed in the first piezoelectric layer and the second bridge is disposed in the second piezoelectric layer.

32. An electrical filter comprising the BAW resonator as claimed in claim **20**.

33. A bulk acoustic wave (BAW) resonator, comprising:

a cavity provided in a first layer and having a perimeter bordering an active region of the BAW resonator;

a distributed Bragg reflector (DBR) bordering the cavity, the DBR comprising the first layer and a second layer, wherein the first layer comprises a low acoustic impedance layer comprising a first layer of silicon carbide and the second layer comprises a high acoustic impedance layer comprising a second layer of silicon carbide;

a first electrode disposed over the cavity;

a first piezoelectric layer disposed over the first electrode;

a second electrode disposed over the first piezoelectric layer;

a second piezoelectric layer disposed over the second electrode;

a third electrode disposed over the second piezoelectric layer; and

a bridge disposed between the first electrode and the third electrode.

34. A BAW resonator as claimed in claim **33**, further comprising a substrate disposed beneath the second layer of the DBR.

35. A BAW resonator as claimed in claim **33**, wherein the bridge is disposed over the distributed Bragg reflector and at least partially overlaps the distributed Bragg reflector.

36. A BAW resonator as claimed in claim **35**, wherein the BAW resonator has a second perimeter bordering the active region of the BAW resonator, and a second bridge is disposed along the second perimeter.

37. A BAW resonator as claimed in claim **33**, wherein the bridge at least partially overlaps the cavity.

38. A BAW resonator as claimed in claim **33**, wherein the bridge is a first bridge, and the BAW resonator further comprises a second bridge disposed between the first electrode and the third electrode.

39. A BAW resonator as claimed in claim **38**, wherein the first bridge and the second bridge each comprise a fill material having acoustic impedance.

40. A BAW resonator as claimed in claim **39**, wherein the fill material comprises one or more of a dielectric material, a metal, or an alloy of metals.

41. A BAW resonator as claimed in claim **33**, wherein the first layer of the DBR comprises a plurality of sub-layers wherein each of the sub-layers has a thickness substantially equal to an odd multiple of the quarter wavelength of the fundamental eigenmode of the BAW resonator.

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